THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE NINETY-THIRD GENERAL MEETING of the Institution of Petroleum Technologists was held in the Rooms of the Royal Society of Arts, John Street, Adelphi, W.C., on Tuesday evening, April 13th, 1926, **Sir Frederick W. Black, K.C.B., B.A. [Lond.]**, (Past-President) occupying the Chair.

The Secretary announced that the following gentlemen had been elected Members of the Institution:—

Members.—Donald Clinton Barton, Stanley James Millar, George Edward Remington, Cyril Thomas.

Tranference to Members.—Ralph Peter Bolton, Charles Erik Capito, Sidney Leonard Mainprize.

Associate Members.—Alan Geoffrey Birkett, Albert Edward Broué, Reginald William Lane Clarke, William Buckhout Goldey, Richmond Barlow Hobson, Andrew Marsden, Willie Moore, David Leo Samuel, Charles James Wright.

Transference to Associate Member.—Stanley Rhys Say.

Students.—John Douglas Bing. Guy Surtees Dilley, Arthur Geoffrey Faithfull.

Associates.—Vere Borlase Burgoyne, Edward Livermore, John Murray, Arthur James Pegg, Ernest George Thorn, George Scott Urquhart.

The Chairman apologised for the absence of Sir Thomas Holland, the President, who, after attending the Council Meeting, had been called away to attend a meeting of the Optical Convention at the Imperial College.

In the absence of the Author, the following Paper was read by Mr. Arthur Heaton:

The Oilfields of the Maracaibo Basin.

By CAMPBELL M. HUNTER, O.B.E., M.A., A.M.Inst.C.E., F.R.G.S., F.G.S. (Member).

THE Maracaibo Basin is a horse-shoe shaped area, bounded on the west, south and east by mountain ranges, which are offshoots of the main Andean system, and on the north by the Gulf of Venezuela or Maracaibo. Within this area are situated the State of Zulia and parts of the States of Mérida, Táchira and Trujillo. Geologically, the State of Falcon also falls within the Maracaibo

Basin, though topographically it lies outside to the eastward, between the sea and the mountains which flank Lake Maracaibo on the east. Roughly, the area embraced by the Maracaibo Basin is about 25,000 square miles, or 33,000 square miles if the State of Falcon is included.

The climate and vegetation within this wide area varies considerably, ranging from barren semi-arid districts in the north to dense tropical vegetation in the south.

Historical.

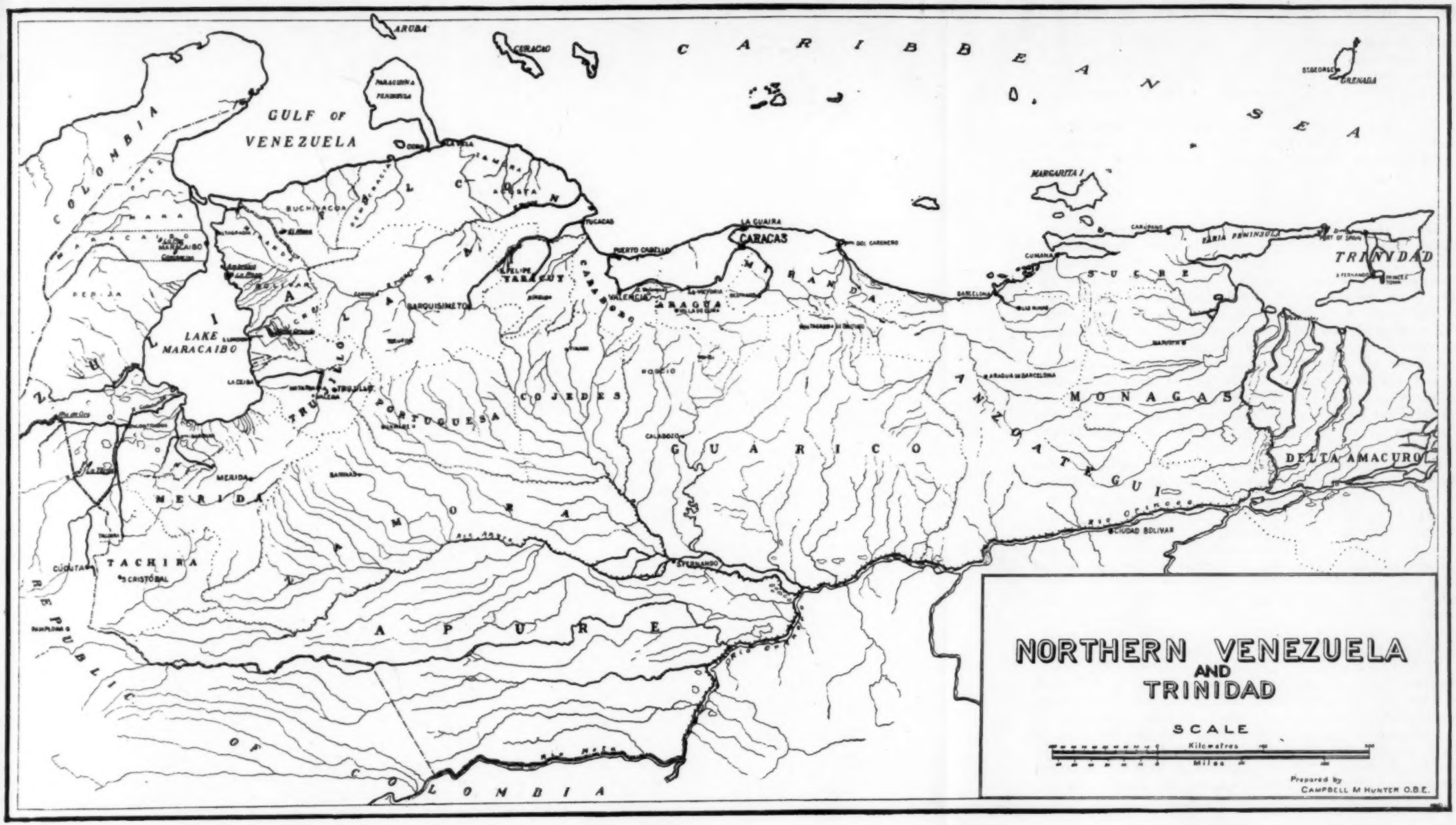
Whilst the occurrence of oil seepages in Venezuela has been known since the early days of the Spanish occupation, it was not until 1878 that the first concession was granted by the Venezuelan Government to the Compañia Petrolera de Táchira. This grant covered a tract of only 100 hectares, about 247 acres, in the State of Táchira, from which the company derived a sufficient production of very high grade oil from seepages to warrant the erection of a small refinery.

In 1907 the Vigas Concession was granted, covering approximately 4,500,000 acres, in the District of Colon, in the State of Zulia, lying south and south-west of Lake Maracaibo. Subsequently this concession was acquired by the Colon Development Company, which is now controlled by the Royal Dutch-Shell Group.

In the same year a concession was granted to General Antonio Aranguren for the development of asphalt in the District of Bolivar in the State of Zulia. This concession has since been extended so as to include the right of exploiting petroleum. Towards the close of 1913 the Aranguren Concession was taken over by Venezuelan Oil Concessions, Limited. The concession comprises the entire District of Bolivar on the east side of the lake, and the District of Maracaibo on the west side, the combined area amounting to approximately 3,000 square miles.

The Planas Concession, covering the entire District of Buchivacoa, in the State of Falcon, was granted at the same time (1907), and, after being on offer many years, was acquired in 1913 by the Venezuela Falcon Oil Syndicate. The concession, covering an area of approximately 3,000 square miles, was transferred in 1918 to British Controlled Oilfields, Limited, which concern has since sub-leased certain portions to other companies.

A concession, covering 300 hectares, roughly 750 acres, in the Paují District, 30 miles south-eastward of Lake Maracaibo, was granted in 1909. This was acquired in 1916 by the Compañia Anónima de Minerales Petroliferos del Rio Paují, who, in turn,


ARUBA
CURACAO
CARIBBEAN SEA
GULF OF VENEZUELA
COLOMBIA
PARAGUANA PENINSULA
LAKE MARACAIBO
MARACAIBO
BUCHIVACOA
FALCON
LARA
YARACUY
PORTUGUESA
BARQUISIMETO
SAN FELIPE
TARACUY
COJEDES
VALENCIA
ARAGUA
CARABOBO
PUERTO CABELLO
LA GUAIRA
CARACAS
MIRANDA
MARGARITA I.
CARUPANO
CUMANA
BARCELONA
ANZOATEGUI
MONAGAS
SUCRE
PARIA PENINSULA
TRINIDAD
PORT OF SPAIN
GRENADA
DELTA AMACURO
GUARICO
APURE
MERIDA
TACHIRA
SAN CRISTOBAL
CUCUTA
BARINAS
CALABOZO
ZARAZA
ORITUCO
CIUDAD BOLIVAR
Rio Orinoco
Rio Meta
REPUBLIC OF COLOMBIA
NORTHERN VENEZUELA
AND
TRINIDAD
SCALE
Kilometres
Miles
Prepared by
CAMPBELL M HUNTER O.B.E.

transferred it in 1920 to an American company which is now developing it.

It was not, however, until 1912 that any serious exploration work was undertaken. In that year the Caribbean Petroleum Company, affiliated with the General Asphalt Company of Philadelphia and the Royal Dutch-Shell Group, acquired from the General Asphalt Company the Rafael Max Valladares Concession, which had originally been granted in 1909. The concession called for exploration of a vast area, out of which 1028 lots of 500 hectares each were selected in the extreme western and eastern parts of the Republic of Venezuela. After the completion of the preliminary survey in the autumn of 1913, drilling operations were commenced early in 1914 on the area known as the Mene Grande Field, some 11 miles inland from the small village of San Lorenzo, on the eastern shore of Lake Maracaibo, some 70 miles south-east of the town of Maracaibo.

The last important concession of magnitude in the Maracaibo Basin area was granted in 1922 to Sr. Delfino, and covers the entire surface of Lake Maracaibo. The area of this concession is 1,159,000 hectares, or nearly 3,000,000 acres. After various vicissitudes this now forms part of the properties of the Lago Oil and Transport Corporation, an American concern, recently formed under the auspices of the Pan American Eastern Petroleum Company to take over and consolidate the properties owned by the Lago Petroleum Corporation and the Lago Oil and Transport Company, Limited.

In addition to these large concessions numberless grants or contracts of 10,000 hectares each have been taken out, with the result that practically the entire area represented by the Maracaibo Basin is now held under exploration or prospecting licences.

Petroleum Laws.

The broad conception of the Venezuelan Government in dealing with its vast potential oil resources has been that of stimulating and encouraging foreign capital to come into the country. The laws relating to concessions have been framed on bold, simple lines, with the result that, within comparatively few years, more active prospecting and development work is taking place in the Republic than in many other countries that have been developing their oil resources far longer.

Briefly, concessions are granted for a period of forty years, with three years given for preliminary exploration work. At the end of the exploration period half of the area under concession

has to be returned to the Government and is treated as National Reserve. These National Reserves are now turned over to a Venezuelan company, called the Compañia Anómina Venezolana de Petroleo, whose policy is to re-lease such National Reserves or enter into drilling agreements for their development.

A royalty of 10 per cent. on production is payable at the option of the Government either in cash or oil. It is, however, provided that this royalty shall not be less than 2 bolivars per ton, or, say, 6 cents U.S. currency per barrel. In the case of lands situated more than 250 kilometres, say, 150 miles, from the sea or Lake Maracaibo, the royalty is reduced to 7½ per cent.

Geological.

The Maracaibo Basin corresponds with a vast geosyncline, the centre of which is occupied by Lake Maracaibo. The mountain ranges surrounding the area on the west, south and east are composed of igneous and metamorphic rocks, while the upturned edges of the formations flanking these mountains belong to Cretaceous and Tertiary ages. Around the periphery exposures of Miocene beds abound, their outcrop of about 400 miles around the Basin being marked by numerous oil and gas seepages. Several of these are of great extent, notably that at Mene Grande, which forms a hill rising about 100 feet above the level of the plain and covering an area of 600 acres.

The stratigraphy of the Maracaibo Basin presents many features of interest, to appreciate which it is necessary to consider the general tectonic stresses to which the area has been submitted. A study of the trend of the different structures within the area shows that these have been caused by at least two sets of earth movements—one of which was responsible for the original Andean system, and which in this part of Venezuela has caused the main mountain ranges to run roughly northeast-southwest; while the second set of forces appear to have been exerted from the northward. Where these latter have superimposed the Andean movement they have resulted either in extensive cross-faulting or in the bending round of the folds until ultimately they assume an east and west direction.

The structures to the west of the Lake, in the Districts of Mara, Maracaibo, Perijá and Colon, are disposed in a general north-northeast and south-southwest direction. South of the lake, and north of the Mérida Range of mountains, the structures lie parallel with the mountain range, which there runs northeast-southwest. Eastward of the lake, in the Districts of Trujillo and

Sucre, and especially in the District of Bolivar, the structures begin to show the influence of the northern or "Caribbean" tectonic system. After being faulted and bent to the westward, the great Mene Grande-Curacao anticline abruptly veers off to the north-eastward, after which it assumes an increasingly easterly direction. One of the interesting features of this Mene Grande-Curacao anticline is the development of spurs or lobes at right-angles to its axis, which were brought about by the southward pressure exerted by the "Caribbean" thrust forces. It is on these lateral structures at Ambrosio and La Rosa that the large wells struck by Venezuelan Oil Concessions, Limited, Lago Oil and Transport Corporation and Venezuelan Gulf Oil Company are situated.

While the conditions attending the deposition of the Tertiary and Cretaceous beds within the Maracaibo Basin would appear to have been ideal, and to have been prolonged without interruption over a considerable period of time, as indicated by the great thickness of the beds, similar conditions would appear to have been present during the period of their compression into the present structures. Thus, one of the characteristics of all the structures within the Maracaibo Basin is their great lineal development, coupled with, for the most part, their gentle angle of dip. Owing to massive Quaternary deposits in the District of Perij , west of the lake, it has been impossible as yet to trace the known structures any great distance. But there is strong evidence that these will be found to extend for many miles. Southwest of the lake, the anticlines known as Rio de Oro and La Tarra have each been traced for upwards of 50 miles. Along the Rio Poco anticline, which parallels the Mérida Range in the south, oil seepages are reported over a distance of about 100 miles. Eastward of the lake, the Mene Grande-Curacao anticline can be traced for about 60 miles, along which numerous seepages are found. Again, in the State of Falcon, although insufficient geological work has as yet been done to determine the length of the various anticlines, it is probable these will be found to link up into several long parallel folds.

Generally, the peripheral or parallel nature of these structures to the mountain ranges surrounding the lake is highly suggestive that the several folds found westward of the central area of the basin will in time be found to have their equivalent expression in the eastern portion of the area. Much valuable light should be thrown on this interesting point when the survey of the lake bottom is completed, as, already, soundings taken near the shore have been found singularly helpful in deducing underground structures, both in the La Rosa and Ambrosio areas.

Major Oilfields.

In view of its having been the first to be systematically developed, the Mene Grande Field deserves first mention, though, as regards output, the La Rosa Field is now of greater importance. The Mene Grande Field, which is operated by the Caribbean Petroleum Company, a Royal Dutch-Shell subsidiary, is situated some twelve miles inland from the lake, with which it is connected by means of a narrow guage railway. The anticline on which this field is situated extends southward from the great asphalt mountain at Mene Grande, and consistently good results have been obtained along its entire extent. The approximate distance between the more northerly and southerly wells is 5 kilometres (3 miles), while its present east and west width is 3 kilometres (2 miles). No dry holes have as yet been drilled within this area, and large producing wells continue to be struck both to the south and eastward. A striking feature of this field is the remarkable vertical depth of 1800 feet, down which the oil producing series has been followed, without as yet any indication of edge-water. Up to the end of 1925 some 18,000,000 barrels of oil had been shipped, equivalent to an average of nearly 315,000 barrels per well. Of the 60 odd wells drilled to date, four had yielded, to the close of 1925, 398,000 tons, 259,000 tons, 364,000 tons and 108,000 tons respectively; the last well being the southernmost on the property, and the production given is that for six months only, at the end of which it was still flowing at the rate of over 700 tons a day.

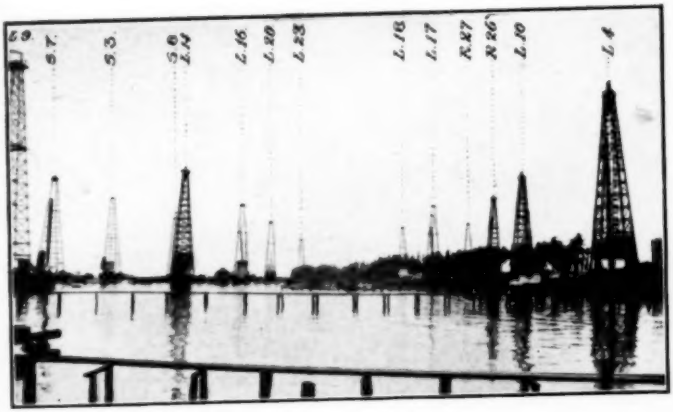
The wells range in depth between 1000 and 2700 feet, and until recently were drilled by cable tools with mud circulation. The rotary system is now displacing the cable tools, and is giving encouraging results.

The oil in the Mene Grande field is of an asphaltic nature, with a gravity of 16½°Be., equivalent to ·956 specific gravity. The field is connected by two pipe-lines to San Lorenzo, where the company has a refinery, whence the crude and other products are shipped by lake steamer to Curacao and elsewhere.

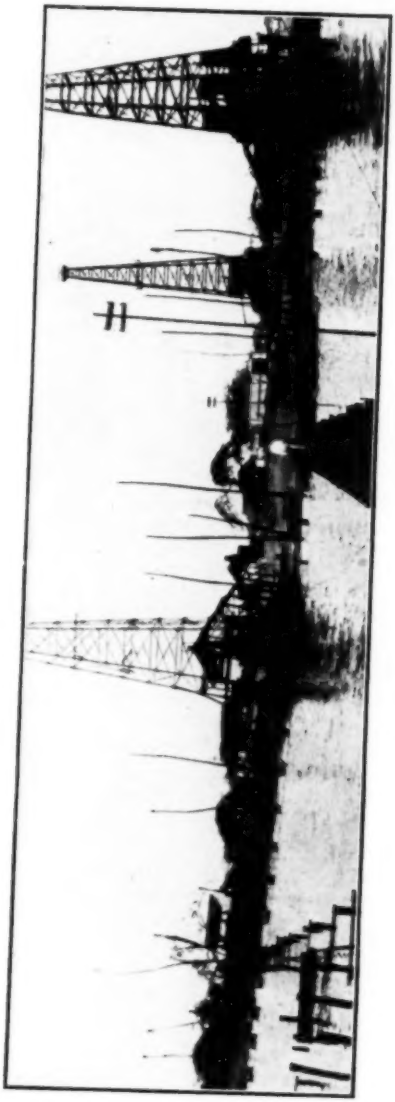
La Rosa Field.

This field is located on the east shore of the lake, about 27 miles southeast of the city of Maracaibo. Unlike the southern fields, the climatic conditions at La Rosa are good, as it lies just within the semi-arid zone of Northern Venezuela. The first well at La Rosa was started in 1915, but no development of any importance took place until 1922, when Barroso No. 2 was brought in at a depth of 1495 feet, and flowed a million barrels in nine

BARROSO WELL NO. 1.



LA ROSA FIELD, LOOKING NORTHWARD.



FIRST WELL DRILLED IN LAKE MARACAIBO.

days. The success attaching to this well furnishes another example of the fortune which may attend oil prospectors, since it had been commenced eight years previously and abandoned at a depth of 900 feet. It was only in 1922 that drilling operations were resumed, apparently with a view to utilising the derrick, which had been left standing when the well was shut down. With the completion of this remarkable gusher, which undoubtedly constitutes the turning point in the oil industry of Venezuela, a tremendous impetus was given to oil activity in the neighbourhood. Thus, the Lago Petroleum Corporation at once started drilling on its Maritime Concession in the lake, opposite the little village of La Rosa. The success which attended this well is now historic, and has resulted in about 125 wells having been drilled to date in its immediate vicinity, the resultant production from which, to the close of 1925, amounted to 12,000,000 barrels, exclusive of that of Barroso No. 2.

As previously stated, underground structural contours show this field to be situated on a lobe or spur structure at right angles to the main fold, whose axis lies about 20 kilometres inland. Initially, wells, after passing through the Tar Sands, were brought into production in the so-called La Rosa sand. It was not till the middle of 1925 that a deeper sand, called the Santa Barbara, was discovered. The first well to encounter the new horizon was R. 28, of the Venezuelan Oil Concessions, Limited. Unfortunately, the well came in out of control, with the result that the gas became ignited from a boiler house some hundreds of yards distant. Several derricks were destroyed, and drilling operations were greatly retarded. Since then, a sand intermediate between the La Rosa and Santa Barbara sands has been discovered, though up to the present it has not been found possible to determine its richness.

The deepest producing wells so far drilled in the La Rosa district only amount to 2600 feet, and as there is no sign yet of edge water having been encountered, it would appear that the field is capable of considerable extension into the lake as well as to the north and southward.

Up to the present the field has been proven over a north and south distance of 6½ kilometres (4 miles), while its greatest east and west development amounts to 2½ kilometres (1½ miles). Within this area no dry holes have as yet been drilled. The wells come in at anything from a few hundred to as much as 15,000 barrels per day, while gas pressures of over 800 lbs. have been recorded. The handling of these big wells calls for considerable skill, since the oil is associated with from 3 to 5 per cent. of fine sand. So far, gas separators have not been found very successful, owing to the large volume of sand brought up with the oil, and

the wells are therefore allowed to flow into open pits, tubular gas separators being introduced at the end of the flow lines.

La Rosa Field presents a scene of more than usual interest, since most of the wells are situated in the lake. Narrow board walks connect the wells with each other and to the mainland, while the boiler houses are built on piles. From the point of view of transport, wells in the lake enjoy distinct advantages over those on land, especially during the rainy season, but, as drilling proceeds further out into the lake, other problems, such as separating the sand from the oil, will call for careful technical study.

Ambrosio Field.

The discovery of the Ambrosio Field reflects highest credit on the geological staff of the Lago Petroleum Corporation. The first well in this area was located about 1300 metres from the shore and at 1380 feet it came in under tremendous gas pressure, after penetrating the Tar Sands for a few feet. So far, six wells have been brought in within this area, all of which confirm the great richness of the La Rosa sand, below which, so far, no well has been drilled.

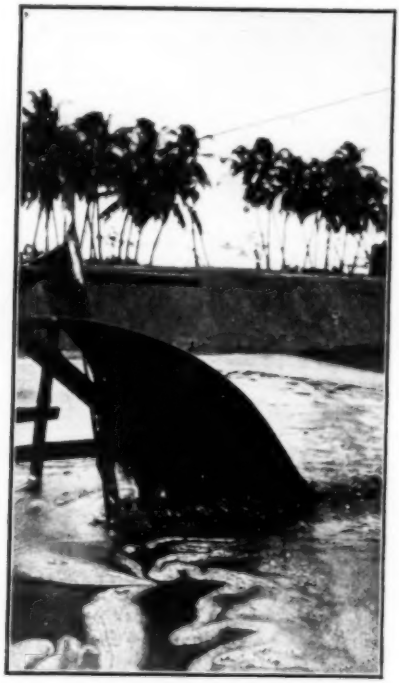
The development of the Ambrosio Field presents many interesting problems, since the minimum depth of the lake at this point is 12 feet. The first impression one gains of the Ambrosio Field is suggestive of the Grand Lagoon at Venice, with countless piles driven apparently haphazard, though on nearer approach they are found to be in ordered regularity.

El Mene.

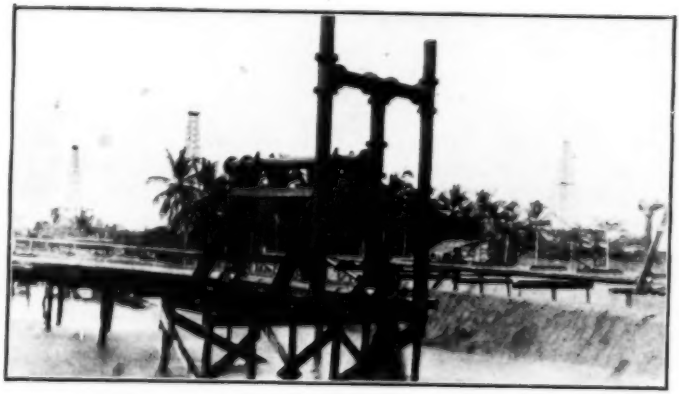
This field is situated some 33 miles inland to the eastward of the village of Alta Gracia, on the east shore of the lake, nearly opposite to the City of Maracaibo. One of the greatest difficulties that has to be overcome in the development of this field was that of transport, which during more than half the year was a matter of almost superhuman effort, owing to the swampy nature of the ground. Shortly a narrow gauge track will be completed to the field, after which it should be possible to rapidly extend its development. The topography and scenery at El Mene represent a distinct contrast both to that at La Rosa and Mene Grande, since the country is hilly and broken, and being near the arid zone the vegetation is not so rank as it is further south.

Drilling initially commenced on this field close to the large oil seepage, and it would appear that the first interpretation of the structure was that the anticline trended southward from that

LA ROSA FIRE, JUNE, 1925.



LA ROSA. WELL FLOWING INTO OPEN FLOW PIT.



FLOW PIT WITH FLOW LINES AND TUBULAR GAS SEPARATOR.

point. At any rate, the early wells were mostly congregated southward of the seepage, and it was not till Well No. 15 was drilled a little to the westward that the first strike of importance was recorded.

Cable tools are exclusively used on this field. Drilling is easy and the wells average from 800 to 1200 feet in depth, the oil series being about 200 feet thick. The quality of the oil is remarkable, having a specific gravity at 60° F. of ·850. On distillation by steam it yields about 35 per cent. of petrol and 38 per cent. of kerosene.

In addition the crude is said to contain about 5 per cent. of aromatic bodies, which distil over in the petrol fraction.

The production of El Mene Field to the end of 1925 amounted to approximately 4,400,000 barrels, with about 50 wells in production.

An interesting geological feature of this field is its determination on the north by a very well-defined east-west fault. This fault may possibly be the extension of the great fault which passes through the Island of Toas, at the mouth of the narrows leading into Lake Maracaibo.

La Concepcion.

The discovery of this field redounds highly to the credit of the geological department of Venezuelan Oil Concessions, Limited, as there were no surface indications of oil or other rock exposures. Attention was first drawn to the area through its lying topographically at a slightly higher level than the surrounding country, after which numberless pits were dug to a considerable depth. From these, valuable geological information was derived which led to the determination of the structure. The first well drilled more than confirmed the geological forecasts, and the subsequent drilling has extended the field considerably. The oil is of a high grade character, not unlike that at El Mene.

Cable tools are used on the field, and the production is pumped through a 17-mile 6 in. pipeline to the terminal at Punta Piedras, some few miles south of the town of Maracaibo. As indicating the richness of this field, a well recently completed, C. 27, came in with a production of 235 tons in the first 35 hours, through a 1 in. flow plug, while well C. 25 produced 75 tons in 7 hours through a 1½ in. flow plug.

La Paz.

This lies 20 kilometres (12 miles) to the westward of La Concepcion, or 45 kilometres (28 miles) from the town of Maracaibo. The field is characterised by extensive asphalt deposits, which

indicate the trend of the structure as running north north-east to south south-west. The character of the oil encountered is heavier than that of La Concepcion, though of a slightly better quality than that of the La Rosa Field. Cable tool drilling is resorted to, and wells with an initial flow of from 200–400 tons per day are encountered.

Rio Palmar.

This field is situated in the north-west corner of the district of Perijá, about 50 kilometres (30 miles) W.S.W. of the La Paz Oilfield.

Unfortunately the first well, on striking oil, was ordered by the courts to be shut down, owing to its location being outside the area of the concession of the operating company. The well is reported to have come in at a depth of approximately 1227 feet, and the oil was said to have flowed over the top of the derrick with considerable violence. The litigation which followed the completion of the well has now been happily settled, and it is hoped that this field will before long come in for systematic development.

Rio de Oro.

This lies about 75 kilometres (47 miles) W.N.W. of the town of Encontrados on the Catatumbo River in the District of Colon. Drilling was first commenced in 1915, the well having furnished a good production at under 1100 feet, the gravity of the oil being about 27° Be, specific gravity ·892. Several other wells have since been drilled, and the geological information collected points to the structure being of great importance and likely to furnish considerable quantities of oil. Like the Tarra anticline, lying some 63 kilometres (40 miles) to the south eastward, its production will probably have to be pumped to Encontrados, from which point it can be handled in barges down the River Catatumbo.

Tarra Field.

Situated 50 kilometres (30 miles) S.W. of Encontrados, this field is of special interest since its structure extends into Colombia. Drilling operations have been carried on during the past ten years, the wells being located on the northern end of the anticline, where up to the close of 1925 some 11 wells had been drilled. One at least of these is reputed to be good for 2000 barrels a day, the gravity of the oil being about 30° Be., specific gravity ·875. Results so far obtained indicate that the field should furnish a considerable production.

A WELL BLOWING WILD.

AMBROSIO FIELD. DISCOVERY WELL ON EXTREME LEFT.

EL MENE FIELD.

FLOWING WELL, EL MENE FIELD

Undoubtedly both the Rio de Oro and the Tarra Fields are destined to play an important part in the future development of the oil industry of the Maracaibo Basin.

Southern Fields.

While several prospecting wells are in the course of drilling on structures lying to the south of Lake Maracaibo, no important results have so far been obtained, probably due to the wells having not as yet been carried to a sufficient depth. As stated above, extensive oil seepages occur in this area, which sooner or later will undoubtedly receive close attention and should result in important new fields being opened up.

Transportation.

Owing to the mouth of Lake Maracaibo being obstructed by two shallow bars, the shallower of the two permitting vessels drawing only 11½ feet to enter, all oil produced within the Maracaibo Basin area has to be handled in shallow draft tankers, which discharge their burden at some convenient spot outside the lake. The most highly developed ocean terminal is that of the Royal Dutch-Shell group in the Island of Curacao, where, in addition to extensive storage, a large refinery and cracking plant has been erected. The round trip from La Rosa to Curacao and back occupies four days.

The San Nicolas ocean terminal of the Lago Oil and Transport Corporation in the Island of Aruba should shortly be completed. At present the lake tankers of that company discharge their cargo into one of two "mother" or "depot" ships moored off the Island of Aruba, alongside which ocean-going tankers receive their cargo. This arrangement has worked remarkably smoothly since it was first initiated, nearly 800,000 tons having been handled in this way. The round trip from La Rosa to the Island of Aruba takes three days.

Several companies, including the Venezuelan Gulf Oil Company, have acquired ocean frontage on the west coast of the Peninsula of Paraguana.

Venezuelan Production.

The remarkable progress in the development of the oil industry of Venezuela is reflected in the following statement, which shows that within the comparatively brief space of six years, an annual production of close on 20,000,000 barrels has been developed.

PRODUCTION OF PETROLEUM FROM THE MARACAIBO BASIN.
(*Barrels.*)

Year	Caribbean Petroleum Company.	British Controlled Oilfields Limited.	Venezuelan Oil Concession Co., Ltd.	Venezuelan Gulf Oil Co., Ltd.	Lago Oil and Transport Co.	Total.
1920 ..	452,002	—	—	—	—	452,002
1921 ..	1,429,543	—	—	—	—	1,429,543
1922 ..	2,187,139	3,883	588	—	—	2,191,610
1923 ..	3,524,877	—	479	—	—	3,525,356
1924 ..	4,776,540	1,012,480	2,637,523	—	414,871	8,839,414
1925 ..	6,250,000*	3,375,000*	3,300,000*	1,750,000*	4,460,000*	19,135,000*
	18,620,131	4,391,363	5,938,590	1,750,000	4,874,871	35,572,925

* Productions for 1925 are approximate.

At the present rate, there can be little doubt that the production of the Maracaibo Basin will substantially exceed 30,000,000 barrels in 1926, and, therefore, place Venezuela as the fifth if not fourth largest producer in the world.

CONCLUSION.

The object sought in this paper has been to give a general hresentation of the oil industry in the Maracaibo Basin as it stands to-day. Already so much development work has been accomplished on the major oilfields that highly informative monographs could be written of each. Similarly, the geology of the area has been so far elucidated that in several districts drilling can now be undertaken on a large scale with every assurance of success. Yet analysis of the successes achieved shows these to have been the outcome of infinitely detailed geological study of the areas in question.

Without the assistance and collaboration of the managers and local staffs of the various oil companies, notably those of the Lago Oil and Transport Company, the Royal Dutch-Shell interests, and the British Controlled Company, this paper could not have been written, and as such the author tenders to them his sincere thanks.

DISCUSSION.

THE CHAIRMAN, in opening the discussion, said that although all the members greatly regretted the absence of the Author, the paper had been read in his absence by Mr. Heaton so clearly and with such emphasis that it had been an extremely easy matter to follow the description of the oilfields of the Maracaibo Basin. He thought the paper would appeal in the first place to those

who valued historical records of progress and general descriptive matter. He was equally certain that there was a good deal in it that would appeal to the geologist, particularly those who were actually acquainted with Venezuela. Venezuela used to be a word that cropped up a great deal during the War when he was over in New York. At that time he had some very interesting discussions with the Departments of the American Government on the subject of transport, in particular whether some barges that were being built in the States for Venezuela could be employed effectively there to add to the production of oil for war purposes. It would be noticed that the paper did not include figures for the production of oil in Venezuela during the War years, the table commencing with the year 1920. That suggested that during the War the production was not perhaps enough to affect the volume of oil that might have been added to the quantity that America sent over to this country. On the other hand, the figures for the past two years, and particularly the figures prognosticated for 1926, were extraordinarily significant. He thought in addition the members would take due note of the variations in the quality of the oil found in different parts of the field, on which he hoped something would be said in the course of the discussion. That point was brought before the notice of the members of the Institution some time ago in a paper on the Trinidad oilfields. He did not know whether the fact that Trinidad was somewhere in the neighbourhood of Venezuela might be considered by geologists as creating any relation between the two fields. It was a little extraordinary, except to those members who were acquainted with the kind of oil drilling described in Venezuela, to have a picture put on the screen showing the surface of a lake, and to have that described as "an oilfield." Drilling in water was not altogether unknown, as he had seen it himself in the States. He supposed, however, the time was coming when the strait of Sea between Trinidad and Venezuela might be dotted with derricks and shown to the members at some future date as "an oilfield!" He particularly desired to request the members not to allow the absence of the author to deter them from criticising the paper or asking any questions in regard to it, because a report of the proceedings would be sent to the author and his reply to the discussion would appear in the Journal of the Institution in due course. He had the greatest pleasure in proposing a hearty vote of thanks to the author for his paper, and to Mr. Heaton for reading it.

The resolution of thanks was carried by acclamation.

Mr. D. A. Sutherland thought the paper was of particular interest because, as the author stated in his concluding paragraph,

it gave a general summary of the position of the oil industry in the Maracaibo Basin as it stood at the present time. He understood that owing to pressure of work the author had not, however, been able to give all the attention he would like to have done to the paper, as he had been unexpectedly summoned abroad. He did no think it was the author's intention in writing the paper to do more than open the subject for discussion. As Mr. Campbell Hunter very truly said, it would be possible to write a complete monograph on any one of the major fields referred to in the paper. The position of Venezuela as one of the leading oilfields of the world was so very important at the present time that he thought it could be honestly said that, great and important as the developments had been in that country, the oil areas had as yet barely been scratched. A very large increase in the volume of production might certainly be looked for. He hoped that when the author was able to give further information he would be able to add particulars regarding the structure encountered in the area being drilled by the Lago wells. That was an area which was characteristic of a great deal of Venezuela. A geologist could not see very much on the lake, nor could he see much in a great deal of the area surrounding the Maracaibo lake. Unfortunately in Venezuela the land was very flat round the lake. Round about La Rosa there were very few exposures. It was a marvel to him how one of their esteemed colleagues, who died last year, Mr. George B. Reynolds, could have arrived so unerringly at his decision in regard to the location of the wells. Very great credit was due to him for the work he did in bringing in those wells. He desired in that connection to correct a statement made by the author in regard to No. 5 well. If it was to be inferred from what was said in the paper that the work on the well was suspended because Mr. Reynolds abandoned hope in regard to it the inference was incorrect. The site of the well was carefully chosen by Mr. Reynolds, and work on it was merely suspended owing to the pressure of undertakings during the war and other contingencies. In ordinary circumstances the well would have been carried down until oil was obtained. Mr. Reynolds's selection was justified because the phenomenal so-called "Discovery Well" of La Rosa was brought in. Before that time Mr. Reynolds had produced data and calculations which had been remarkably borne out by the results obtained, and a tribute was due to him for his pioneer work, not only in Venezuela but in Persia where his first work was carried out. Mr. Reynolds carried out his work in Venezuela under extreme difficulties, in a country which at the time was very little developed. He knew that, because he (Mr. Sutherland) followed Mr. Reynolds very shortly afterwards, going over the same area with an expedition to the east coast of Venezuela. It was very easy

for anyone to go over that area at the present time and to criticise what was done in the early days. Mr. Macrorie, who accompanied him on the first expedition and did most excellent work at that time on the geological side, would bear him out in the statement that it was not an easy task to find one's way through the country in those days. At that time the country had not been opened up, and the difficulties to be overcome were such that it took eight days to go from Maracaibo to El Mene, whereas at the present time it was possible by means of the road, that had since beeen made, to travel between those two places by motor in one-and-a-half hours. The work that was carried on in the country at the time showed very clearly that the regularity of the outcrops of the folds parallel to the ranges was very well marked. For a distance of fifty or sixty miles it was possible to trace the anticlinal belt upon which El Mene was situated, exhibiting a more or less domal tendency, and with a number of parallel folds, side by side, such as were indicated in the paper. The difficulties in regard to transport did not relate simply to the swampy nature of part of the ground, but were two in number. In the dry season the sandy part of the area, which extended from Maracaibo for a distance of 15 to 20 miles, was in a state of eternal dust. The wheels of vehicles sank into the ground, and the difficulty experienced in keeping the tractors in condition, was no mean task. It was found as a matter of fact that the life of a 10-ton tractor of the best class could not be taken at more than six months. A little further on the ground was clay, which was ideal in the dry season when in contrast the sand gave so much trouble. But in the wet season, when the sand was firmly set and made a good road, the clay seemed to give way altogether. There was a light crust on the top, through which the wheels of the tractors went deep into the mud. All this had to be faced and means of drainage devised, but the difficulties practically remained unsolved. They could only be solved by the construction of a railway line, which was now almost completed. In the earlier days of the development of El Mene they could take in nothing heavier than a small Canadian rig, with which six of the wells were drilled. There was never any idea that the extension of the anticline was thought to go to the south as suggested in the paper. As a matter of fact in the original reports made by Mr. Macrorie and himself they pointed out quite clearly the construction, which was exactly the line on which the drilling had subsequently taken place. In point of fact Well No. 15 was within 200 yards of the original Discovery Well, the first well drilled on the field and the first to produce oil, and was on the same anticline. In the course of exploration it was necessary to test the south dipping flank of the structure but there was never any dubiety as to the course of the anticlinal belt. A

great deal of work still remained to be done there. He did not think the State of Falcon could be described as exactly typical of the Maracaibo Basin, because the moment the foothills of the Falcon district were reached distinct geological strata were found. No mistake could be made when traversing these beds, it was possible to trace all the clays, marls, sands, and sandstones, and, especially to the east, the limestone ; and it was possible to place the whole geological series right back as one went into the field. It was quite a good lesson in geology to go out and work backwards from the younger to the older series. There were distinct anticlinal structures ; in the next place there were very well marked faults, and there were monoclines which could be mapped and traced. It was quite different from the case at La Rosa, in which the geologist walked over a plain on which the geological structure was not so obvious and had to be determined or confirmed by pitting. Another very great difference was that in the El Mene district a high quality of oil was produced. The oil was of very high grade indeed, containing a very large percentage of gasoline and very light oils. It was true also that at La Concepcion a light oil was now being obtained, but it was characteristic of most of the oils at Lake Maracaibo that they were of a heavy asphaltic nature. He had always believed, and still believed, that the study of the geology of the district was only in its infancy. He believed that with the deeper drilling that he had advocated for some years on the Buchivacoa concession further results would be obtained. Some boring results at El Mene showed oil containing a high percentage of paraffin wax, and he believed that deeper drilling would reveal a horizon which was exposed as one went east in Buchivacoa. One of the great difficulties in El Mene and some of the districts of Buchivacoa was that of obtaining water supplies. Very early in the work it was seen that there was a chance of tapping water sands. In the first exploration well that was drilled water was produced at 400 ft. to the extent of 400 or 500 barrels a day. That had continued, and from a series of wells an excellent supply of fresh water was now obtained. The camp had now increased in size to such an extent that it had gone almost beyond that, and it was necessary to make dams and get water from the river. One of the geological difficulties that had to be faced in Venezuela was that of obtaining key fossils. In the search for fossils these seemed at first almost conspicuous by their absence, but a fair number had been found, and latterly more and more had come to light. Sufficient palaeontological evidence however, had not yet been obtained to correlate all the strata found in the districts referred to in the paper, and a great deal of work in that connection still remained to be done. He thought also that the author had paid a great

tribute to the fairness of the laws of Venezuela. There was every encouragement for people to go to Venezuela, and he only wished that more British companies could be seen taking advantage of the opportunities which the Americans were fast taking to secure a foothold in Venezuela. It was a very important factor in the case that concessions were granted and that on the whole the royalties were comparatively light. There were many problems yet to be faced before the district of Maracaibo, and the Venezuelan oilfield in general was as fully developed as it must ultimately be. For instance, besides the land transport there were difficulties on Lake Maracaibo itself where unfortunately there were shallow depths with only 11 ft. of water, one at the entrance to the Lake and another a little further in, and that would always be a handicap until a pipe line was constructed to carry the oil out to the deep water. Of course plant and machinery could be got in. On the geological side there were a few other points he would like to raise, but it was very difficult to deal with the area as a whole. There was no possibility of making accurate correlations at the present moment, and we still await detailed paper on one or other of the areas involved. He had in contemplation with one of his colleagues the reading of a paper, when he obtained permission, on the Buchivacoa district, and until that time came he did not think any further remarks on the subject would be of value.

Mr. Charles Dabell said he had been particularly interested in the slides shown of the producing wells. He did not think a slide of a well had been seen on the screen that evening which was not flowing absolutely freely, showing a terrific waste. He would have thought that in these days, especially out in Venezuela, with American appliances so handy, such a waste of the lighter and also of the heavier products could have been obviated. Apparently they had not much to learn from Americans on the question of bringing in large wells, judging from the slides that had been shown. Mr. Sutherland had referred to the fact that he would like to see more British companies operating in Venezuela. Personally he thought one of the main difficulties in regard to small companies going to Venezuela was the question of the lake transport. It must be obvious to all the members that it was necessary to have marine transport to get the oil out of the lake region.

Mr. Sutherland said he quite agreed with the remarks which had just been made. It would be remembered that in the discussion he recommended very strongly, as he had done for several years past, the laying of a pipe-line to deep water on the coast of Venezuela, but that required a great deal of capital.

Mr. Dabell said one point he would like to know was the approximate rise and fall of the lake. Personally he could not see

at the moment how it would be possible to harness Nature for the purpose of getting the oil out of the lake. He was quite prepared to believe, however, that highly skilled engineers might evolve some scheme for harnessing that power.

Mr. Sutherland said the rise and fall of the lake was only about 3 ft., although it varied in the dry season. In the wet season a tremendous amount of fresh water came in, and that was why it was difficult to remove the bar, because there was the force of the sea water in the dry season pressing into the lake, and in the wet weather the fresh water rushing down into the lake, shifting the sands in the channels at the lake entrance.

The Chairman said the only further remark he wished to make was that he noticed in the paper that in one field a well was described as coming in out of control, and in another field apparently an Order from the Law Courts was very effective in shutting down a particular well. He did not know if that happened very generally in Venezuela.

Mr. Arthur Heaton, in reply, said that Mr. Campbell Hunter would be glad to receive the informative remarks that had been made by Mr. Sutherland and Mr. Dabell, and personally he would make a point of forwarding them to the author so that the members might have the benefit of his reply.

The meeting then terminated.

Mr. Basil F. Macrorie wrote:—Dealing with the stratigraphy of the Maracaibo Basin, Mr. Hunter emphasises the consideration of the general tectonic stresses to which the area has been subjected for the proper appreciation of the features of interest in the geological structure. On my first visit to Venezuela, in 1918, I studied Herman Karsten's memoir with geological map (scale of 1 inch to about 120 miles) on Panama, Ecuador, part of Peru, Colombia, Venezuela and part of the Guianas. My thoughts were thereby led back to a general consideration of the initial shrinkage of the earth's surface not only in the comparatively small area of the Maracaibo Basin but over the larger expanse of the whole of the Americas. The old analogy of the wrinkling of the earth's crust to that of the skin of a shrivelling apple suggested that the original main wrinkles were not parallel lines round the circumference nor of equal magnitude throughout their full courses, but probably would adopt sinuous courses and varying magnitudes. Therefore it is not necessary to assume that because the strike of the main uplift in both North and South America is longitudinal, the latitudinal strike of the folding in Central America and in the Caribbean area was imposed at a different epoch from that of the folding of the North and South wrinkles. Rather it would appear

that the two main foldings were contemporaneous and the initial shrinkage imposed its strikes on all subsequent subsidiary wrinkles. The first crumpling of the earth's crust would have appeared to have caused the formation of a wide shallow basin extending from about Latitude S.15° to as far at least as Latidude N.20. Subsequent folding divided this Basin into at least four subsidiary troughs :—(1) The Caribbean Basin ; (2) The Orinoco Valley Basin ; (3) The Amazon Basin ; and (4) The Basin extending westwards from between Grenada on the north and Trinidad on the south to the Gulf of Maracaibo. The eastern end of this Maracaibo Basin would only be separated on its southern shore from the eastern end of the Orinoco Basin by the narrow northern range of Trinidad, remnants of its northern shore being shown in the Goajira headland and in the Paraguana Peninsula, its further continuance being suggested by the belt of shallow water extending eastwards to Grenada. The northern shore of the larger Caribbean Basin is suggested by the east and west strike in northern Guatemala, which strike also persists in the greater Antilles.

Sir Frederick Black raised the question as to their being any relation between the oilfields of Trinidad and those of the Maracaibo Basin. The great similarity of the light Tabaquite oil with that of El Mene in Venezuela, and of the heavy oils of Trinidad with those of the Maracaibo Lake, the fact of the heavy oils being found in the younger Tertiaries and the light oils in older rocks in both oilfields and finally a lithological similarity in the sedimentaries, all suggest that the oil-bearing strata were being deposited under similar conditions and during the same geological ages both throughout the length of the Maracaibo and also of the Orinoco Basins. It would also seem likely that the later folding movements were contemporaneous throughout both Basins and the suggestion is that the "spurs" or "lobes," mentioned by Mr. Hunter, are due to promontories of the original continent bordering the Maracaibo Basin.

A tabular section of the strata as reported to outcrop in the eastern part of the State of Falcon gives the sequence and downward order as follows :—(1) Loose sands, sandy clays and shales, sandstones, thin clay bands and heavy oils found within the group. (2) Mainly massive sandstones with subordinate sandy shales, no oils reported ; (3) Stiff clays, some hard calcareous sandstones, calcareous clays and limestone lenticles. Light gravity oils at various horizons in the groups.

At Coro, about halfway across the State of Falcon, an oil-bearing limestone outcrops. This was euphemistically named, by some geologists in Venezuela, "The Dam Site" limestone. Coral limestone, heavily saturated with oil, has been found at La Realidad

some 15 miles eastward from El Mene, but no limestones outcrop at El Mene. In 1923 no correlation of the Coro limestone with the La Realidad limestone had been established probably because geological knowledge of the intervening country was "euphemistically" too meagre to permit of it.

Samples from the El Mene wells show a tendency to become more calcareous with depth, which suggests that the oil-bearing horizons are what have been termed in America "fore-runner" sands to a main oil series at greater depth.

Mr. Hunter refers to the main fault on the north side of the El Mene field. This is probably the continuation of or a rider to the big fault which determines the northern face of Mount Lejia, which is the height overlooking La Realidad. To my mind one of the most interesting geological features is that which appears to be what is termed in America "a plunging nose." It was not until the end of 1922 that the late Mr. W. M. Norris produced a map indicating this structure, and in January, 1923, he and I chose the site for Well No. 15 in this "plunging nose" area which well thereafter proved to be the first commercial success of the El Mene field. The anticline eastwards from this structure is sharply folded in the crestal area, dips ranging from 30° up to 50° or more for a distance of 250 metres down the southern flank, then the strata suddenly flatten out to dip gently. Outcrops of the rocks at the west end of the crestal area indicate a steep plunge of the anticline to the west, but, further to the west and south-west occurs a wide expanse of almost horizontal strata, and it is from this part of the field that practically all the present production has been obtained. The structure does not seem to comply exactly with the definition of a "plunging nose," but rather might be described as a "plunged terrace," since the almost flat structure continues over a distance of at least two kilometres to the south-west with a width of about one kilometre. It is significant that this structure occupies the intervening area between where the El Mene anticline (with its east to west strike) ceases and anticlines to the south of El Mene (with a north to south strike) begin. Mr. Hunter indicates that the "spurs" or "lobes" in the Maracaibo Lake region occurs similarly at points where the folding begins to change from a longitudinal to a latitudinal strike.

Consideration of the Maracaibo and Trinidad oilfields leads to the suggestion that oilfields should be discovered at some future date in the valleys of the Orinoco and Amazon Rivers.

Mr. Campbell M. Hunter, in a written reply, said he was very gratified by the interest shown at the meeting in his paper. At the same time he deeply regretted, owing to his absence in Venezuela, not having been able to take part in the discussion.

Reference had been made by some of the members to the difficulties presented in moving oil from the Maracaibo Basin Area. In actual practice, no real difficulty was experienced, in fact, the circumstances that all the oilfields surrounded the Lake had enabled production to be moved in the most economical manner possible, and with the smallest capital expenditure, by means of shallow draft tank steamers. Undoubtedly were the entrance to Lake Maracaibo to be dredged sufficiently to enable the entry of large ocean-going tank steamers, transport questions would be still further simplified. Under existing conditions, the oil, after being piped to lake side, was conveyed in shallow draft lake steamers, having a capacity of about 16,000 bls. to various ocean terminals, such as on the Peninsula of Paraguana and the Dutch West Indian Islands of Aruba and Curacao. At these points the oil was either transferred into land storage tanks, or, as at Aruba, into a mother ship or floating depot, from which ocean-going tankers were subsequently laden. The economy of this arrangement will be realised when it is appreciated that costs of lake transportation over a water distance of 140 miles is less than 15 cents per barrel, whereas the corresponding cost by pipe-line would be nearly double that figure.

Reference had been made to the wells apparently flowing absolutely freely, and as such presumably showing terrific waste. This impression, gained from one of the slides, was fortunately erroneous, since all the wells were brought in under control, being allowed to flow through "beans" or chokes rarely exceeding 1⅛ in. in diameter. Owing to the heavy sand content of the wells, it had been found impossible to flow wells directly into closed storage tanks, though measures advocated by the author were being developed with a view to effecting important economies of gas, while also limiting the evaporation of the lighter oil constituents. Bearing in mind the enormous pressures sometimes encountered in the early days, when the Companies were still in the prospecting stage, the number of wells that came in out of control was remarkably small and reflected the greatest credit on the technical staffs. Thus even in the case of the Barroso discovery well, which flowed at the rate of 100,000 barrels a day for nine days, most of this oil was saved by hastily improvised dams. One of the interesting experiences enjoyed by the author during his visit to Venezuela in the autumn of 1925 was that of a well flowing wild into the Lake, (see illustration, p. 244), owing to the sand in the oil having cut through the bonnet of the master valve. Even under these unusual conditions, practically every drop of the oil was saved, as the water over an area round the well was enclosed by a canvas apron attached to piles driven by hand whilst the well was flowing.

The written communication from Mr. Macrorie was of exceptional

interest, especially that portion in which Mr. Macrorie outlined his views regarding the formation of several large basins as the result of longitudinal and latitudinal shrinkage of the earth's crust. This broad conception throws an important light on the orientation of possible new oil areas, and is worthy of further development.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE NINETY-FOURTH GENERAL MEETING of the Institution of Petroleum Technologists was held in the House of the Royal Society of Arts, John Street, Adelphi, London, W.C. 2, on Tuesday, May 25th, 1926, the chair being taken by the President, Sir Thomas H. Holland, K.C.S.I., K.C.I.E., D.Sc., F.R.S.

The President said that a meeting of the Students' Section would be held at Aldine House on Tuesday, June 1st, at 6 o'clock, when a paper would be read entitled "Essential Qualities of Various Petroleum Products," by W. B. Rowntree. He had also to remind those present that early in October a Conversazione would be held at the Offices at Aldine House to open the new Session.

The Secretary read the list of Members elected since the last meeting, as follows :—

Associate Members.—James Barrett, Wilfred Neill Foster, Charles Ignatius Kelly, John Edward Nicholls.

Associates.—Cyril Spenceley Cleverly, Claude Chapman Jacobs, John Weston Warner.

The following paper was then read :—

Organic Theories of Oil Origin.

By ERNEST CLARK (Student Member).

[This paper was awarded the Students' Medal and Prize, 1924-25.]

In studying the subject of the origin of petroleum one is impressed by the lack of proportion between theory and fact, and it is very evident that progress towards the solution of this fascinating problem will best be assured by the careful investigation and analysis of the facts of petroleum occurrence, not only with regard to the origin itself, but to the closely related subjects of migration and accumulation. In view of the general lack of detailed knowledge, this paper cannot pretend to be other than the sketchiest of outlines; its underlying idea is the unification of existing theories rather than detailed critical consideration of them. The latter course of enquiry is rendered peculiarly difficult because it is unsafe to reason about the origin of one accumulation of petroleum with indiscriminate employment of the evidence furnished by another. There is, of course, the danger of being too inclusive, but in view of the variability of

natural conditions this would seem to be a lesser evil than restriction.

Until we have information as to the relative importance which is assumed by each of the factors operating in the preservation of organic matter in sediments and the degree to which biochemical change is permissible in the transformation to oil, a comprehensive survey of oil origin is impossible.

Of late years, it has come to be generally realised that oil formation is at least as normal a phase of sedimentation as that of coal; and just as coal is the product of decomposition of terrestrial vegetation, so presumably is oil the result of similar decomposition of other organic materials. It is convenient to divide the subject into two parts—deposition and chemical change.

Deposition.—Under this heading will be noted those classes of organisms whose abundance renders them liable to be important constituents of organic deposition, with a brief consideration of the factors controlling the entombment of organic matter in sedimentary deposits.

Plants.—Algæ and diatoms comprise the chief planktonic plants, and there are many benthonic forms; they are abundant in fresh and salt water and are very widely distributed. The seaweeds are mainly marine benthonic types, often of large size and characteristic of the Laminarian zone (0—15 fa); others, such as the Sargassum, are floating forms. The water ferns (rhizocarps) grow or float in fresh water, are most abundant in the tropics, and their spores, etc., are widely distributed by flotation. The grasses are mainly terrestrial and fresh-water, though some are shallow marine benthonic—*e.g.*, salt marsh grasses.

Animals.—Foraminifera are small, abundant typically marine organisms, with many brackish water species, and belong chiefly to the plankton and vagrant benthos types. Benthonic foraminifera are largely confined to shallower seas, favour the muddy facies, and are very prolific.

Corals are typically marine sedentary benthonic animals of the warmer waters; the simple corals flourish in comparatively shallow muddy habitat; the reef builders are more restricted in their distribution and prefer clear oxygenated water.

Molluscs are largely marine benthonic animals, the majority of fairly shallow water habitat and abundant in muddy environment among others.

Fish are marine and fresh-water nekton; like the molluscs they are abundant in the shallow seas and continental shelves, following the distribution of their planktonic food.

Under normal conditions of sedimentation a very small proportion of this teeming organic life is preserved in the sediments, most of it being oxidised after death or serving as the food of living forms.

Both plants and animals consist largely of proteins, fats and carbohydrates in varying proportions, but carbohydrates, particularly cellulose, are more characteristic of the plants, and proteins usually bulk largely in the animals. Though the forms of life are of very different organisation and habitat, there is, on a chemical basis, a degree of uniformity which makes unreasonable the award of pre-eminence to a restricted few in the formation of petroleum. Restriction will depend almost entirely upon environmental considerations. If any distinction for the mother substance of oil is to be made it should be a chemical one, *e.g.*, the fatty substances, owing to their nature and slowness of putrefaction, might conceivably be regarded as a main source—whether they originated in foraminifera or algæ. Some organisms actually contain hydrocarbons, but the percentage is so small as to be negligible.

The richness of organic deposits depends on the relative speeds of three variables, supply of organic matter, its oxidation, and burial by sediment. The second of these actions (oxidation) is in opposition to the others. The supply varies according to the abundance and size of the organisms and their mortality ; commonly a small individual size is compensated by numerical abundance and short life, *e.g.*, diatoms, algæ, foraminifera.

The rate of oxidation of the organic matter depends primarily upon the ease with which the oxygen content of the water is replenished, but varies for substances of different physical and chemical composition, and perhaps, according to the quantity and nature of dissolved substances in the water. It is apparent that here are selective factors capable of segregating substances of similar chemical composition from miscellaneous types of organisms. The resistance of terrestrial vegetation to decomposition under water greatly facilitates the deposition of this class of material.

The replenishment of oxygen at depth is governed by wave action and tidal, temperature, and wind-generated currents, especially those whose vertical displacements are large. The depth effect varies greatly and depends on the power of the currents and the configuration of the basin ; as an example, the sand and mud of the North Sea are kept in constant movement by the waves and tides. In the Black Sea vertical currents are slight on account of the greater density of the deeper water, and at 100 fathoms strongly reducing conditions prevail. In shallow stagnant waters temperature variations may promote vertical currents.

It is worthy of note that fresh water dissolves considerably more oxygen than salt water, and cold water more than warm.

Supply.—The abundance of marine life is determined mainly by the supply of planktonic food, but also by a sufficient oxygen content of the water, and in the case of benthonic organisms by the type of sea floor. Hence those conditions which normally favour a high rate of supply of dead organisms, also favour the rapidity of their oxidation. Conversely a stagnate or sediment-laden environment, facilitating preservation, is generally toxic to life, and is often characterised by stunted fauna. Such an environment usually favours the development of small species; those which can adapt themselves enjoy little competition and are often very abundant numerically.

The association of prolific micro-organic remains with strata which are believed to have produced petroleum is of very frequent occurrence, and due significance should be attached to this fact.

What conditions favour the accumulation of rich organic deposits over long time periods, as appears to have been the case? Abnormal abundance of supply would be assured if the organisms were continuously carried into a toxic environment or the toxic influences themselves ebbed and flowed—as often demonstrated by the colour variations in shales.[4]

Surface currents may sweep the plankton and nekton into waters in which they cannot live; instance the enormous destruction of fish in saline gulfs such as fringe the Caspian Sea.

A continuous supply of dead organisms in some deeper water areas is maintained by young benthonic forms which have been transported by current action during the meroplanktonic stage over depths in which they cannot survive. The meeting of warm and cold currents, or fresh and salt waters are other factors of importance in maintaining a rapid supply of dead organisms.

The deposition of those planktonic organisms which do not readily sink on death may be effected by the precipitating action of mud. Benthonic forms are the most favourably situated with regard to burial and many live partially buried. The seaweed type of marine plants, owing to the numerous air-spaces in their tissue, tend to remain floating until decomposed or cast up on shore, where they sometimes accumulate in abundance in the shallow water muds.

Once the organic matter is buried in mud the restriction of circulation prevents the access of oxygen, and arrests oxidation. A sudden increase in supply of sediment therefore not only causes high mortality among organisms, but ensures favourable conditions for their entombment and preservation. Such fluctuations may

be due to diastrophism or simply to seasonal or periodic variation of climate, and their effect is intensified in the case of gulf or inland sea conditions owing to the focussing of drainage. The occasional deposition of arenaceous horizons over the clays would be a natural result, the more widespread sands being attributed to oscillation of sea-level.

It is apparent that many combinations of circumstances can give rise to an environment favourable for the deposition of organic materials, animal and plant, in marine or, to a more limited extent, freshwater deposits. The irrationality of demanding any particular set of deposition conditions for petroleum origin is evident when it is realised that strength of one factor may effectively balance weakness of another in determining the preservation of organic matter, and the richness of such deposits exhibits every degree of variation. This does not imply that favourable conditions are of universal occurrence, for they appear to be rather specialised, and from general principles, certain types of environment are of particular interest, and some of these it is proposed to examine.

Among sedimentary strata, deep sea deposits are rarely represented, and the large majority of sediments were deposited in the comparatively shallow waters of the continental shelf and epicontinental sea. Study of modern marine faunas indicates that sediments characterised by abundant and varied benthonic remains were deposited in depths of 100 m. or less; a large proportion of Tertiary sediments belong to this group.

The muds of the open continental shelf form under conditions comparatively unfavourable to the extensive preservation of organic life; the current and wave activity is generally unrestricted and the full force of the ocean "swell" and currents is experienced. Life is very abundant, but oxidising and scavenging influences are active, toxic influences restricted, and there is no general cause for segregation of organic material. In spite of this it is common for the argillaceous sediments to contain a small percentage of bituminous material widely disseminated throughout their bulk, and the pyritous nature and blue colour of many of the clays testifies to reduction of iron compounds by decomposing organic matter.

Further restriction of oxidising influences would seem to demand some degree of separation of the body of water from the open ocean. Such conditions are typically represented by epicontinental seas, gulfs and marginal lagoons. In the absence of strong wave or current action, delta formation is possible and therefore favourable circumstances are frequently associated. In such environments the fauna would probably suffer change and perhaps restriction, but the favourable conditions for preservation and

the facility for segregation of the organic materials would tend to counterbalance a possible falling off in the supply.

Coastal lagoons are frequently formed by the configuration of the marine shelf, or by the growth of coral or other reefs. Such waters are shielded from the main oceanic circulation and effectively collect the sand, silt or mud available; they are usually shallow and fairly stagnant and support abundant organic life whose remains are incorporated in the sediments.

When the lagoons are of the coral reef type there is commonly progressive development of reefs seawards as the inner lagoons fill with black organic muds. Under such conditions the black muds creep out and overlie the marls and limestones of the outer lagoons. Stratigraphical evidence proves that such conditions can attain considerable magnitude.[1]

An accompanying stage of marginal lagoons and a feature of flat protected coasts is frequently the extensive development of salt marshes or mangrove swamps, often associated with a considerable littoral fauna. Considerable salt peat deposits may be formed, and though much of this material would produce a high ash coal, the animal organisms would be expected to yield other hydrocarbons, such as petroleum.

Palæo-geographic studies of several Tertiary oilfields indicate the importance of gulf and inland sea conditions in the deposition of petroliferous sediments.[2] Rapid, fluctuating sedimentation, sometimes combined with restricted oxidising influences, render such environments eminently favourable for organic deposition.

Deltas are frequently an associated feature; they are characterised by the very large supply of sediment and its variable composition and deposition, resulting in the extreme lenticularity of deltaic deposits. The large supply of organic material and its rapid burial effectively defeat oxidising influences. To the landward, terrestrial vegetal deposits may form in the swamps and marshes, and offshore the muddy sediment flocculated by the salt water, buries up marine organic materials together with the more easily transported terrestrial forms (leaves, spores, etc.).

During the wet season the supply of sediment usually increases by several hundred per cent., exterminating and covering a large proportion of the marine offshore fauna and flora, and pushing the sands and clays further outwards. Small vertical movements would cause large horizontal transgression of conditions owing to the flat nature of the topography, and interbedded carboniferous and petroliferous strata might be produced.

The proportion to which terrestrial vegetation participates in the deposits is governed mainly by the quantity of this material which is available—*i.e.*, by climatic conditions. The bulk of

such material would normally be deposited on or near the delta fan. In the absence of suitable climate, and therefore of extensive development of terrestrial vegetation, the marine fauna and flora would constitute the chief source of supply. Often delta and vegetation are partly due to the same cause—a humid climate.

The redeposition of oil itself in association with mud particles has been noticed[3]; and the coagulation in salt water of the soluble organic matter (humic acids, etc.) accompanied by colloidal silica in some rivers, may contribute to the organic materials.

In considering all these natural phenomena it is important to remember that the balance of influences which constitute an environment is constantly changing, due to their own operation; *e.g.*, unless the infilling of a gulf by sediment be constantly offset by subsidence, the gulf will gradually disappear. Slow subsidence not only increases the areal extent of an environment, but allows the deposits, especially those of deltaic or shallow lagoon characters, to attain considerable thickness. The subsidence effect will, however, largely depend on the original topography of the areas involved.

Limestones.—Objections to limestone as an oil mother-rock appear to have been based on the slowness of accumulation of many rocks of this type, owing to the scarcity of terrigenous material, implying that all organisms would be decomposed aerobically long before burial could occur. The geological circumstances of the occurrence of some petroliferous limestones, however, strongly suggest an indigenous origin for the oil or bitumen, though in other cases it may be equally apparent that the limestone merely acts as a reservoir. The formation of limestones demands comparative freedom of the waters from terrigenous sediment, but this does not necessarily imply extreme slowness of sedimentation, [27] some terrigenous sediment often accompanies the calcareous matter when marls are formed. The reefs determining the lagoonal type of limestone environment in warm seas are often associated with coral growth; there is abundant supply of organic matter of many kinds, comparative rapidity of sedimentation of coral "sand" and chemical precipitate, and calm water. Given restricted oxidising influences, there is no reason why organic matter should not form a constituent of calcareous deposits, and modern shallow water calcareous deposits often contain a small percentage of unoxidised organic matter.[6]

The organisms, both during life and by their decomposition, cause heavy precipitation of carbonates in the lagoons, and it has been shown that such a precipitate contains variable proportions of magnesia[5]; the formation of dolomite is favoured in the deposit itself and by replacement in the cavernous reefs. The

decomposition of the organisms is accompanied by the formation of sulphides and ammonia compounds; the latter assist the precipitation of carbonate, and the former, in the absence of iron, impregnate the deposit with hydrogen sulphide and doubtless organic sulphur compounds are formed. An oil resulting from the residual organic material would be rich in sulphur with the probability of a dolomitic mother rock.

Limestone oils generally exhibit peculiarities which may be partially genetic, such as a high sulphur content usually associated with asphaltic nature.

In considering the possibility of indigenous limestone oils, the facility of vertical and horizontal migration of fluids in a limestone rock as a factor assisting the concentration of a small percentage of disseminated petroleum, cannot be overlooked. The occurrence of argillaceous horizons within the limestone would greatly influence this segregation.

Salt.—It is an interesting question as to how far the almost universal association of brines with petroleum is significant of the original depositional conditions. The composition of the brines has not been so exhaustively studied as their distribution, but characteristic differences from modern sea water are increased salinity and deficiency in sulphates.

If the brines are original and have not suffered great concentration they would indicate arid conditions, probably one of two general types:—

(1) Leaching of older sediments into drainless dry basins—a modern example of which is the Dead Sea.

Under such conditions, as the water became more saline the life would be greatly impoverished and increasingly difficult to deposit, on account of the higher density of the brine. There is, however, the possibility of the salt assisting segregation by preventing the dispersal of colloidal fatty compounds during decomposition.

(2) Saline gulf type: gulfs with periodic or permanent shallow connections with the sea, allowing water to flow in to replace evaporation, but with little or no outflow, consequently becoming increasingly saline if the climate is sufficiently dry.

All organisms carried into such a gulf would be killed, ensuring an ample supply of organic matter, in one case continuous, in the other periodic. The supply of sediment would probably be confined to wind-blown sand and dust and to chemical precipitation. The formation of gypsiferous organic deposits may be explained in this way: such conditions, however, require a peculiar combination of circumstances, whose balance is very easily upset,

and they would hardly be expected to be of common occurrence in an intense form.

It is more than possible, however, that petroleum brines were originally normal connate waters which have been partially altered. When a sediment is deposited on the sea floor it is saturated with salt water ; compaction and uplift cause circulation of the connate fluids, and meteoric fresh water tends to dilute and discharge the brine, except from deeper structures or enclosed lenses. During its movements underground the brine may suffer changes in composition and concentration due to solution of rock constituents and reaction with them.

The high salinity may in the first place be due to electrolytic concentration of the dissolved salts of sea water in the pore spaces of the fine sediments,[7] or to the formation of secondary hydrated minerals subsequent to deposition.

The deficiency in sulphates may be a genetic association due to the reduction of sulphates to sulphides which normally accompanies bacterial decomposition of organic matter in sea water ; iron pyrites is a familiar result. Sulphates may also be reduced by chemical interaction with the less stable hydrocarbons of petroleum,[8] yielding carbonates in which some brines are rich.

The almost universal association of petroleum with brine may be due not only to the fact that meteoric waters usually dissolve the salts from sediments, but that where meteoric circulation is possible oil and gas tend to be removed.

Coal and Oil.—It may be regarded as proved that coal is essentially the product of terrestrial vegetation, deposited in peat bogs and marshes or transported under marine or freshwater conditions. Marine animal and plant life are the only other types of organic matter which can form an important constituent of sediments, and petroleum is likewise the other form of hydrocarbon occurring in sedimentary rocks ; hence a close connection between the two would be surmised and this is supported by the following generalisations :—

Petroleum occurs more commonly in rocks of marine origin and is intimately associated with their connate brines.

It is chemically possible to obtain petroleum from most types of organic matter, and presumably under such conditions as occur geologically.

With these premises it is possible to form some idea of the depositional relationship of oil and coal, and possibly by comparison and test, to learn more of both.

Although it is possible for coal- and oil-forming conditions to vary laterally into one another it is by no means essential, for the coal may be formed from upland peat bogs with no associated

marine equivalent, or in land swamps when conditions offshore are unfavourable to organic accumulation. Even in the case of coal formed from transported materials, the preservation of other life may be small. On the other hand, offshore conditions could be quite favourable for accumulating marine or fresh water organic life associated with the leaves, spores and resins of the terrestrial vegetation. Such conditions would also favour the development of marshes already discussed.

But such environments probably represent a small proportion of those favourable for organic accumulations, and it is evident that the majority of marine organic deposits would form without contemporaneous terrestrial plant accumulations. Therefore, though coal deposits might vary laterally into, or be interbedded with, petroliferous sediments, the majority of petroleum deposits would not be associated with coal—a relationship which agrees well with the observed facts and supports the original contentions.

Oil Shales.—There is much uncertainty regarding the nature and origin of oil shales ; the problem is mainly a chemical one, the geologic aspects of which may be considered here. The chief peculiarity of oil shales is the variable content of yellow or brown organic material known as kerogen, which yields petroleum rich in unsaturated hydrocarbons and sometimes in sulphur compounds, on destructive distillation. Distinctive properties of the shales such as lightness, toughness and resistance to weathering are ascribed to this substance.

Owing to the fact that kerogen frequently exhibits spore structures identical to those in the translucent yellow portions of coal and cannel sections, and that coal frequently passes laterally through cannel into oil shale, and that oil shales are abundant in coal measures,[9] it appears that the kerogen of many oil shales consists of the more easily transported plant structures such as spores, spore exines, resin and pulp, deposited in lagoons and lakes of the coal swamps, or offshore in marine clays ; such spores and resins are particularly resistant to decomposition. These substances also form an appreciable proportion of many coal seams and may be partially responsible for the petroleum oils produced by low temperature carbonisation.

Kerogen is a highly unsaturated compound ; its decomposition is mainly endothermal,[10] is accompanied by the separation of much free carbon, which in specific instances cannot be detected below 250° C. ; redistillation reduces the total unsaturation of the crude and increases the volatiles. Many oil shales have been subject to more than usual depth and thrust pressures, but the kerogen shows

no evidence of decomposition, and the shales contain no free oil except in the locality of igneous intrusions.

Other shales, notably those of marine origin, often contain a small percentage of free oil with the kerogen, indicating admixture of organic materials; salt water decomposition may be indicated by the abundant iron pyrites in the shales.

It would appear that kerogen shales are much more closely related with coal than with petroleum; their relation to petroleum is therefore similar to that of coal, although the greater similarity of facies would indicate a somewhat closer association. The geological occurrence of oil and oil shales does not support a strong genetic relationship,[11] but little evidence appears to be available on the subject.

EXAMPLES.—The genesis of petroleum is the most fundamental factor governing its occurrence; in an ideal case, three zones may be identified in the field:—

(*a*) Mainly arenaceous strata, deposited under conditions unfavourable for the preservation of organic matter.
Interbedded argillaceous rocks increase in proportion towards zone (*b*)

(*b*) which is mainly argillaceous, with thin sandy horizons and sand lenticles. Petroleum formed in the clays would be concentrated in the sands, and it is evident that, other indications being favourable, structures on this area would deserve full investigation.

(*c*) Almost completely argillaceous strata, perhaps favourable for the formation of petroleum, but not for its accumulation in restricted areas unless permeability has been subsequently induced, or major sand horizons have persisted.

The Californian fields have been exhaustively studied by Arnold and Anderson, who find conclusive evidence that the oil originated within diatomaceous Miocene shales. The oil is found in a whole series of formations ranging from Eocene to Miocene, but the essential factor for the existence of petroleum seems to be the presence of the Monterey shale or its equivalent either above, below or in contact by faulting or unconformity with the producing sands. The Monterey shale contains an abundance of the remains of diatoms and foraminifera, and it is impossible not to connect these organisms with the source of the petroleum. Further, the Monterey is the source of oil only where it is diatomaceous, elsewhere the shales and the sands in contact with them are barren of oil.

In the Coalinga field the Montereys are absent, but their place is filled by the Tejon shales which are similarly abundant in diatomaceous and foraminiferal remains, where they are associated with oil.

In the Californian fields, therefore, there is strong evidence that the oil originated from micro-organisms in strata deposited under marine conditions.

In Trinidad, most of the production is obtained from a series of marine sands and clays. Cases exist where there can be little doubt that the oil is indigenous to marine clays, rich in foraminiferal remains. The lignitic series is separated from the underlying oil-series by thick non-lignitic strata.

In considering the question of coal and oil association, it should be borne in mind that disconformity or any evidence of earth movement between the deposit of the petroliferous and carbonaceous series, renders the assumption of similar original environments extremely unsafe.

In India, the petroliferous series are Tertiary sediments, which were apparently deposited in three great gulfs, ultimately silted up to form large river valleys. The oil occurs towards the deeper portions of the gulfs, and coals and lignites are characteristic of the coastal areas. Both here and in Borneo there is interbedding of the petroliferous and carboniferous strata, but without any passage from one to the other being observable.

In Rumania the petroliferous series are of brackish water type and contain bands of lignite. The Salifére consists of oil impregnated salty clays and shales, presumably formed under lagoon conditions, and the adjacent Pliocene sands are large oil producers. It is thought that petroleum also originated in the Meotic, for which the Salifére intrusions have chiefly a structural significance.

In Pennsylvania there is a marked disconformity between the coal-bearing Pennsylvanian series and the oil-bearing Mississippian series. A small amount of oil occurs in the coal series, but no coal is found in the oil series.

In the Northern Mid-Continent fields there is closer association of coal and oil, but most of the oil is obtained from the pre-coal series.

Therefore, although the geological association of coal and oil is evident in some important fields, it is not so universal as to form, in itself, a conclusive argument for the similar origin of both.

In this respect it cannot be overlooked that petroleum, formed in rocks which are now geologically old or disturbed, has had every opportunity of migrating to the surface and becoming lost. It may be for this reason that petroleum is only found in Palæozoic rocks where folding of a very gentle nature has occurred, as in the Pennsylvanian and Mid-Continent areas.

It would appear that no common theory is sufficient to explain the origin of all petroleum deposits, but that each deposit must be judged on its own merits. Such a conclusion is inevitable

when the wide possibilities of variation in sedimentary conditions are considered and, further, serves to explain the chemical diversity of various oils.

The factors which determine the ultimate composition of a crude petroleum may be classified as follows:

The nature of the parent substance, its environment and deposition.

The types of chemical reaction which transform the organic matter to petroleum hydrocarbons.

The modifications caused by contact of the petroleum with rocks and underground waters during migration.

Whatever variation of opinion there exists with regard to the details of the processes involved in the generation of petroleum, there can be no doubt of certain general conclusions based on broad geological and chemical facts.

It is useless to assert, for instance, that marine environments do not provide conditions for the preservation of organic matter, when the bulk of the world's oil supply is derived from sediments of marine origin.

The diversity of petroleum-forming conditions is demonstrated by the varied chemical nature of this substance, and association with strata of many sedimentary types, but the characteristic petroliferous properties of widespread stratigraphical horizons proves that such conditions were often attained on a grand scale.

In the formation of oil pools the concentration of oil in the mother rock is of secondary importance to the facility with which it is transferred to the porous horizons and there segregated. Owing to lack of this latter factor, the bulk of the world's petroleum remains uselessly disseminated as a small percentage of the sediments in which it was formed.

When the temporary nature of oil pools is realised, the number that await discovery and development, and the small overall extraction in the past—possibly less than 10 per cent.—some conception of the comparative normality of the petroliferous phase of sedimentation is obtained.

Chemical Change.

The first chemical changes which occur in the organic matter are undoubtedly putrefactive, in most cases aerobic at first, in others anaerobic from the commencement. Bacteria living under anaerobic conditions may derive their oxygen from the organic substances of which it is a constituent, forming hydrocarbons and organic sulphur, nitrogen and phosphorous compounds—chiefly hydrides. The chemical effect of bacteria seems to be due

to the catalytic action of the enzymes which are produced; and anaerobic bacteria can cause oxidation or reduction according to the presence of hydrogen or oxygen acceptors. The bacterial changes are accomplished rapidly, compared with the exceedingly slow geological distillation or devolatilisation due presumably to weight and thrust pressure[12] and assisted by depth temperature.

The chief problem is to determine the stage to which bacterial action carries the organic matter in its transformation and to what extent geochemical action is operative. The researches on coal formation have demonstrated that cellulosic plant materials yield a slow continuous evolution of gases rich in hydrogen—chiefly methane, which results in the formation of carbonaceous solid residues yielding a high proportion of aromatics on destructive distillation. In the formation of petroleum different types of substances are involved and it is not known whether these would yield heavy hydrocarbons as a first stage by elimination of carbon dioxide and water, or if methane would represent an intermediate product and the heavy hydrocarbons the result of its polymerisation. In the latter case a bituminous residue would be expected.

That the geochemical process is not a simple pressure-heat distillation is indicated by the lack of a common vertical gradation of oils in the field, even allowing for the influence of other factors in determining the grade of oil. The type of oil seems to be essentially a stratigraphical character rather than a vertical one, although the non-occurrence of asphalt-base oils below those of a paraffin-base in any single pool[13] may have a genetic significance.

It is probable that geochemical action is frequently operative because of the arrestment of biochemical change by the production of antiseptic substances, resulting in a correspondingly different product. It is, however, known that some types of bacteria can exist in hydrocarbons and decompose them.[30]

In considering the chemical changes of organic matter, it is of importance to recall that this material is largely of a colloidal nature, and that bacterial action is almost entirely concerned with such substances; finally, the clay matter may be largely colloidal.

Remarkably little attention appears to have been given to the importance of the probable admixture of various animal and plant substances in the original organic materials. The differences in chemical nature of these substances must be reflected in variations in the manner and products of their decomposition, but the overall effect of admixture will be a levelling and grading of the types of petroleum.

The general lack of detailed geological knowledge of particular mother-rocks of petroleum is relieved by a few researches, and the important part which micro-organisms such as diatoms

and foraminifera have played in oil formation has been verified.[14] The investigation of modern muds is likewise very incomplete, but there is evidence that animal matter, diatoms, and algae decompose rapidly under anaerobic conditions, and hydrocarbons similar to those occurring in petroleum are formed.[15] That anaerobic bacteria are effective agents in the transformation of vegetal organic materials to coal has been demonstrated by microscopic research[16]; fossil bacteria are known in oil rocks and petroleum has been found in recent bacterial deposits.

The decomposition of organic matter at ordinary temperatures cannot be accomplished without bacteria; their activity in transforming organic matter into oxidised substances is unquestioned, but there is nothing to suggest that they have any predilection in this respect and cannot equally well cause reduction. On the contrary, bacteria flourish alike under aerobic and anaerobic conditions, and the fact that one is more familiar with the former is no reason for doubting the existence of the latter. When aerobic bacteria are deprived of free oxygen they utilise chemically combined oxygen for their life processes; other types can flourish indefinitely without oxygen, indicating that energy is derived from processes other than oxidation reactions; all grades from aerobic to anaerobic exist. By bacterial action, proteins readily break down to amino and other compounds and carbohydrates are convertible into alcohols or even fats, but there is doubt as to the probability of fats going beyond fatty acids, due to the development of antiseptic hydrocarbon substances. The transformation of fats into oil at low temperatures by bacterial action on seaweed has presumably been accomplished however.[18] That fats are the tardiest in undergoing bacterial change is indicated by the increase in their relative proportion in decaying plant and animal organisms in mud.[19] Engler, who obtained hydrocarbon oils from fish oil distilled at about 10 atmospheres and 320° C., concluded that the elimination of the proteins was a necessary first stage in the formation of petroleums, leaving the fats to be hydrolysed, followed by the elimination of carbon dioxide from fatty acids and water from alcohols and yielding heavy hydrocarbons, probably containing oxy-compounds. The various series of petroleum hydrocarbons were derived from side products of these reactions and by the breaking down of the high molecular weight oxy-compounds by geochemical processes.

Nitrogenous bases occur in many crudes,[21] indicating that complete removal of nitrogen compounds is not necessary; nitrogen and carbon dioxide are common constituents of natural gas. Phosphates are difficultly soluble and would largely remain

in the mother-rock; where searched for, they were found in oil, water and sediments, presumably associated with soluble oxidation products of nitrogen bases.[22] The direct formation of heavy hydrocarbons by elimination of oxygen as carbon dioxide and water, at quite low temperatures, is more likely than the polymerisation of methane; for the simplification of heavy hydrocarbon molecules is much easier in practice than polymerisation of the lower paraffins. The polymerisation of unsaturated hydrocarbons by sulphur compounds is readily accomplished, and many asphaltic oils contain a large proportion of thio-asphaltenes.

The extent to which microbian action and carbonisation participate in the chemical changes of the organic substances may largely determine the type of oil produced; it has even been suggested that some plant materials may give either oil or coal,[23] though none of the intermediate grades seem to have been found. It is significant to note that with the passing of years and increased knowledge of the reactions involved, more importance is being attached to bacterial action, due presumably to failure of the older distillation theories to account for the observed facts. Restriction of importance does not constitute rejection however, and it is very probable that much of the natural gas associated with oil is to be ascribed to them, especially where cellulosic materials are concerned.

A logical conclusion of the formation of oil mainly by pressure—heat—time distillation would be an original direct relationship of the degree of metamorphism and grade of oil produced—the distillate varying as the composition of the mother substance constantly altered, *or* presuming methane to be the main product, the degree of polymerisation depending on concentration and pressure. In the Appalachian geosynclinal, the main coal series occurs above the oil series and the degree of metamorphism as measured by the carbon content of the coals (ash free) has been correlated with the grade of oil beneath.[12]

From a map contoured in equal "fixed carbon" lines (isovols) the oil prospects of different areas can be estimated. These results have been interpreted as convincing proof that the petroleum was generated by geological distillation, or devolatilisation mainly of plant organic matter in the carbonaceous shales, and implied a close association between oil and coal formation. Since the coal metamorphism is closely related to the intensity of folding, thrust pressure is presumably the chief cause of devolatilisation.

There are, however, certain difficulties to be explained before such sweeping statements can be accepted. The coal and oil series are separated by an important disconformity, showing that movement of the lower petroliferous series had occurred before

the coal was formed. What justification is there for assuming that the method of sampling and the stated limits have allowed for the important factors, other than regional metamorphism, which influence the C/H ratio? The occurrence of banded bituminous—anthracitic coal seams in Scotland and the detailed evidence concerning the relation of anthracite and other coals in South Wales,[24] shows that the C/H ratio is largely influenced by the amount of preliminary biological decomposition as well as the intensity of geophysical factors. The carbon ratios of cannels are 10—20% lower than of corresponding bituminous coals.[26]

The migration of the heavier liquid hydrocarbons across the bedding of compacted shales is a process difficult to imagine without an active driving force, especially at low temperatures; neither can folding be a possible cause, for the structures of the Appalachian oilfields are extremely slight, and may be due to deposition and compaction effects rather than to horizontal pressure. The oil accumulations are largely due to lithological factors, but gas occupies the anticlinal zones and there is segregation and differentiation of oil, gas and water which must have required a bodily movement of the liquids along the sands.[25] In the absence of meteoric circulation, compaction and folding, it is difficult to explain this movement.

It might be urged that during the immense time interval, the vehicular action of the gas would be sufficient to cause concentration, even with such low dips, but the theory itself demands that lateral movement of the oil be slight.

This question of the extent of migration is of importance because the eastward variation in character of the Appalachian oils can be explained mainly as a migration phenomenon. As the vast pile of sediments compacted, brine, gas and oil was expressed from the clays into the sands, where the lateral movement of liquids from the central area towards the fringe of the geosyncline took place. The superior mobility of the gas allowed it to travel faster than the oil together with the lighter liquid hydrocarbons, with the result that the oils to the east contain an increasing proportion of volatiles and are finally overlapped by the gas. Such a differentiation would be assisted by the depth temperature, extreme flatness of the structures and continuity of the sands.

It will be noticed that, according to this theory, oil-forming conditions are restricted mainly to the broad central area of the geosyncline; gas would be expected particularly in all domes, fringed by oil, which would also occupy terrace and lens traps; the remaining gas continued its migration and now occupies the area to the east. This is approaching the edge of the geosyncline and area of stronger folding; the thrust pressure of which this

folding is an effect may be chiefly responsible for the degree of devolatilisation of the coals and so the grade of oil and metamorphism of coal have been equated to the same cause.

So long as alternative explanations of the observed effects are possible, any sweeping generalisations regarding the origin of the oil will be unreliable. According to the distillation theory oil was presumably formed in the earlier stages of folding in the areas which now contain only gas, and has therefore been almost completely metamorphosed, but no other explanation than migration can account for the further disappearance of the gas itself to leave only residues and traces. For reasons already stated it is improbable that kerogen shales produced oil, and such dynamo-chemical action is only known to produce the lower members of the paraffin series, chiefly methane, so that the direct production of heavy hydrocarbons by geochemical distillation is as much assumption as by any other process. In this case polymerisation cannot be resorted to, for increased pressure results in disintegration according to the theory.

Summarising, therefore, although dynamo-chemical action probably does occur, in the absence of verification it should be held mainly responsible for the lighter hydrocarbons; it is only a partial cause, whose proportional effect is obviously less in younger fields.

Devolatilisation should be distinguished from the other geochemical action resulting in the production of heavy hydrocarbons by elimination of CO_2 and water, though these reactions probably occur together, so long as the second is active.

It is frequently urged that the high gas pressure of most oil pools is inconsistent with the formation of the petroleum approximately contemporaneous with sedimentation. But gas pressure may be due to causes other than generation of gas after consolidation, chief of which is the reduction of pore-space by compaction of the original mud to shale.

Suppose the oil and gas is being formed in the body of a depositing organic mud; the layers of sediment are consolidating according to grade and superincumbent material and the liquids are squeezed towards those areas where relief from pressure is easiest, the oil and gas constituting the disperse phase in brine. Movement of the globules is dependent on the flow of water, and will be more sluggish, resulting in partial concentration of the oil and gas—particularly gas—in the upper layers. Deeper in the series liquids are expressed into the porous horizons, since these probably constitute avenues of relief by lateral flow to low-pressure zones.

A sand is deposited and overlain by more clay; as it becomes more deeply buried, it receives the oil- and gas-rich liquid,

and owing to the pressure at the sub-face always exceeding that at the super-face, will continue to receive liquids in diminishing quantity until consolidation is completed. Thus the globules of oil and gas are flushed into the sands, but, owing to their coalescence in moving through the more open sand, and to the superior surface tension of water, the hydrocarbons are concentrated in the sands at the expense of the clays.

The pressure on the gas and oil in the sands, being capable only of transmission by the liquids so long as the pore-space remains constant, will equal the rock pressure, minus the mechanical resistance to liquid movement in the sand and shale, and the resistance of the shale itself to compression. The resultant pressure will equal the gas pressure in the sands, which will be larger when the gas is segregated, owing to lessening of the capillarity resistance.

When the beds are folded the more plastic clays are squeezed into the crests of anticlines and troughs of synclines, with rock flowage and secondary folding facilitating the exchange of liquids in these zones. The nett result is the enrichment of the sand with oil and the generation of lateral movements of liquids in the strata, directed towards the crestal zones. Without these lateral movements, due to compaction and later to folding, it has been shown that the gravitational separation of oil, gas and water is unlikely to occur.[25] It is therefore probable that where oil accumulations occur in gently folded strata without meteoric circulation, the oil was formed before compaction was accomplished.

In the case of a geosyncline it is evident that migration would be towards the rim, and any oil and gas carried from the central area would be concentrated in the first structural or lithological trap which was encountered, then overflow to the next—a conclusion which agrees well with observed facts.

The main interest of any theory of oil origin hinges about the details of the chemical change of organic matter to petroleum, since it is fairly certain that most types of organic matter may participate. The chief qualifications of such a theory from a geological point of view appear to be: that the reactions can occur at low temperatures, not above 150° C., preferably very much lower; the completion of the reactions before complete consolidation of the sediments is desirable; the decomposition of proteins, carbohydrates, and glycerides must be accounted for, and the elimination from the oil of much of the nitrogen and phosphorus; the genetic significance, if any, of paraffin-, mixed- and asphalt-base crude oils should be explained. There is much to be said for the opinion that the initial stages are bacterial, and after the oils have been formed, a slow yield of gas might be responsible for considerably augmenting the gas pressure.

Finally, the theory should provide a suitable basis for a rational explanation of the transference of the oil from mother-rock to porous reservoir.

The chief avenues of research would seem to be:—

(*a*) Physiographical, involving scientific investigation of sediments which are forming at the present day, particularly such types as are indicated in the first part of this paper.

(*b*) Geological, involving an enlargement of detailed knowledge of the lithology and palæogeography of petroliferous sediments and the factors controlling the movements and behaviour of oil, gas and brine in them.

(*c*) The chemical problems would largely be outlined from the results of (*a*) and (*b*).

Summary and Conclusions.

1. This paper aims at unification of existing organic theories of oil-origin as a foundation for future research. It considers the relative importance and degree of variation of several essential conditions; one group of these concerns the nature and deposition of organic material, another its transformation to petroleum, and a third, often overlooked, the transference of hydrocarbons from mother to reservoir-rock.

2. A natural classification of the organic material rests on chemical rather than biological data; single types of organisms, *e.g.*, *foraminifera*, *diatomacea*, *algæ*, may predominate, but all deposits will contain mixtures. The relative rates of organic supply, oxidation, and sedimentation determine the richness of organic deposits. Slowness of oxidation compensates for slowness of sedimentation (calcareous environment), and conversely (deltaic environment).

Oxidation depends on vertical current action, which is often restricted in gulfs, lagoons and epicontinental seas, where reducing conditions normally occur at shallower depths than on the exposed continental shelf.

3. There are many causes for abnormal mortality, continuous and periodic; among these increase of sedimentation is of prime importance. A small organic content is common in argillaceous sediments; the formation of suitable porous strata and the facility for segregation of oil into them may constitute equalising conditions.

4. The observed geological relationships of petroleum, coal, and kerogen-shale follow naturally from the foregoing considerations.

Connate waters play an important part in expressing hydrocarbons from shale, and oilfield brines represent such waters.

5. Chemical change involves proteins, carbohydrates and fats decomposing under anaerobic conditions by bacteriological and geochemical reactions.

Protein breaks down rapidly, but the high nitrogen content of some petroleum suggests contribution to oil formation ; anaerobic bacterial action gives a mixture of substances including fatty acids. Carbohydrates are convertible into alcohol and possibly fats ; cellulose is relatively stable but gives a slow yield of methane among other substances. Fats decompose slowly and are regarded as of first-rate importance.

6. Geochemical change continues the transformation already begun, the type of product depending on the degree to which each action is operative. Carbonisation produces methane, leaving a carbon-rich residue ; much natural gas is due to this process, but the formation of oil thereby is doubtful.

Direct formation of heavy hydrocarbons by elimination of carbon dioxide and water from fatty compounds, alcohols, etc., is a process confirmed by experimental data. Heavy molecules tend to simplify, producing the constituents of crude oil ; methane, incapable of further simplification, increases proportionately to the degree of metamorphism.

7. On available evidence the relative importance of bacteriological and chemical change cannot be defined, but the following facts are significant :—

There is no undisputed evidence correlating the type of oil with degree of metamorphism.

The segregation of oil and gas into sands remains unexplained on a geochemical basis, but is a natural consequence if petroleum is formed before the clays consolidate ; such rapid transformation would result from bacterial action.

It is evident that a problem of this magnitude, involving specialisation in several distinct branches of science, can only be satisfactorily solved by the closest collaboration of all investigators.

The task of patiently accumulating information relating to oil origin could be admirably carried out by such an institution as this, for it is only by co-operative effort that the collection of adequate evidence to substantiate any general theory could be achieved.

In conclusion the author is deeply indebted to Prof. V. C. Illing for valued criticism and encouragement during the preparation of this paper, and to Mr. H. B. Milner, whose illustrations contributed materially to its presentation.

REFERENCES.

[1] A. W. Grabau, *Bull. Geol. Soc. Amer.* **14**, 337-352.

[2] T. Dewhurst, *Journ. Inst. Petr. Tech.* **10**, No. 44, 402-406.

[3] C. C. Rae, *Trans. Amer. Inst. Min. Eng.*, No. 1137-P, Feb., 1922.

[4] J. E. Marr, *Quart. Journ. Geol. Soc.*, 1925.

[5] F. W. Clarke, "Data of Geochemistry," 1924, 569.

[6] E. W. Skeats, *Bull. Mus. Comp. Zoo.* **42**, 53-126.

[7] K. Andrée, *Geologische Rundschau*, Bd. III, Heft 5-6, 324-360.

[8] G. S. Rogers, *U. S. Geol. Surv. Prof. Paper* No. 117.

[9] H. M. Cadell, "The Oil-Shales of the Lothians," Part I.

[10] R. McKee, "Shale Oil," pp. 74-89.

[11] A. Beeby-Thompson, "Oil Field Exploration," 1925, **1**, 263.

[12] A. Beeby-Thompson, *ibid.*, p. 53.

[13] D. White, *Bull. Geol. Soc. Amer.* **28**, 727.

[14] R. W. Pack, *U. S. Geol. Surv. Bull. No.* 603, 117; *Prof. Paper No.* 116. R. Arnold, *U. S. Geol. Surv. Bulls. No.* 357 and 398. P. E. Spielmann, "The Genesis of Petroleum," p. 66.

[15] Kramer and Spilker, *Ber. Deutsch. chem. Gesell.* **35**, 1212. H. Potonié, *Natur. Wochenschr.* **20**, 599; *Naturwissensch* **2**, 505.

[16] B. Renault, *Bull. Soc. ind. min.* 3me série Tome 13-14.

[17] J. E. Hackford, *Oil Engineering and Finance*, 1922, I., 363.

[18] J. E. Hackford, *ibid.*, p. 365.

[19] Tausz and Peter, *Centr. Bakt. Parasitenk*, II. Abt. 49, p. 497.

[20] C. F. Mabery, *J. Amer. Chem. Soc.*, 1919, 41-I., p. 1690.

[21] Chase Palmer, *Econ. Geol.*, March, 1922.

[22] P. E. Spielmann, "The Genesis of Petroleum" p. 23.

[23] Strahan and Pollard, "Coals of S. Wales Coalfield."

[24] M. J. Munn, *Econ. Geol.* **4**, 141-157.

[25] W. Russel, *Econ. Geol.*, May, 1925.

[26] Dept. of Marine Biology of Carnegie Inst. Vol. 23, 1926. "Some Marine Samples from Pago Pago Harbour"; "Report on Bacteriological Examination of 'Chalky Mud' and Sea Water from the Bahama Banks."

DISCUSSION.

The President said that he did not propose to take any definite line in the discussion, but he wanted to draw attention to one or two features which he hoped would serve as a hint to those whom he would invite to speak. The feature of the paper which struck him first of all was one which had characterised a large amount of the literature about the origin of petroleum—that is to say, it indicated a number of similarities. Possibly if, instead of the grey picture due to points of similarity between the different occurrences, there were brought out strongly in high lights one or two features

of dissimilarity, between, say, coal and petroleum, both as regards their composition and occurrence, there would be a greater chance of inspiration. There was a tendency for men who wrote scientific papers to lay out their facts in the most logical form, to bring the facts together in such a way as to show that no features had been forgotten, and therefore that the conclusions arrived at were entirely judicial. It was quite unscientific—or was supposed to be—to depart from that method, but as a matter of fact, ordinary men did not work in that way. What the research worker usually did was to make happy guesses, destroying many for every one guess which survived. It was just like the law of reproduction in Nature. He was not sure that they would not have had a greater inspiration if just those few features which appealed to the author most had been brought out strongly into relief—exaggerated relief, perhaps, almost caricature; for the basis of caricature was that some outstanding feature was exaggerated in such a way that the leading characteristics of the individual jumped at once into the mind of the observer.

There had been an enormous mass of literature about the origin of oil—and a good deal of it was of as much use as some of the oil deposits which companies now and again were floated to exploit! The task of digging out the features which were of real value must have been a very great one for the author, and the Institution was much indebted to him for the way in which he had gathered together an enormous quantity of reliable data and marshalled the essential features of the problem; also for drawing attention to the principal literature in which these features were discussed. But he must say again that he would have preferred to have had one or two essential characteristics brought out, treated fully, exaggerated even, in order that one might in some way get an inspiration as to the origin of oil. When he recalled the papers read before the Institution, he thought that those which had given rise to the greatest amount of subsequent discussion and criticism, and therefore had been most active in inspiring further work, had been papers which dealt with some outstanding points, or with one point only in the origin of oil—something of the kind, for instance, that occurred in the paper by Mr. Hackford, in which he detected a particular feature and dwelt upon it and suggested that here was an inspiration for the origin of oil. That was not an unscientific way of proceeding at all. One did not necessarily neglect all the other essential features, because one drew out one particular feature in strong relief. The author said at the end of his paper, "It is evident that a problem of this magnitude, involving specialisation in several distinct branches of science, can only be satisfactorily solved by the closest collaboration of all investigators." The

speaker had an idea that there had been very few theories of value in science that had been elaborated in that way. There was, of course, a great deal of necessary collaboration in the building-up of data, but the man who had discovered a law of any value had more often jumped at it by a process of inspiration rather than by working out inductive processes after an accumulation of a large quantity of data. He felt that this subject of the origin of oil involved such an enormous number of features and so many sciences that the most fruitful suggestion would probably be forthcoming rather from the man who looked at it only from one point of view, and brought that point of view into strong relief, instead of attempting to survey the whole field of science and arrange all the known facts in perfect order so as to draw deductions according to the strictest scientific law. That was not possible any more than, for instance, it was possible for one to draw a scientific conclusion from such a statement as appeared in the paper in which the author referred to the activity of bacteria, especially anærobic, in forming residual organic matter into petroleum. The author said "fossil bacteria are known in oil rocks and petroleum has been found in recent bacterial deposits." He gave that as a sentence which showed that any attempt to gather together the whole of the facts in a short paper left one with a series of what might be called logical unconformities. Fossil bacteria were known in oil rocks; for that matter, bacteria were also found in human beings, in great numbers, but it was not suggested that that was the origin of mammalian life. Here a sentence was taken out as significant, but it was by no means the natural consequence that because bacteria were known in oil rocks they had anything to do with the making of oil. The bacteria might have been implanted in the rocks before the oil was formed, while it was forming or after it had been formed, without having anything to do with the formation of petroleum. He selected that example only to illustrate how futile it was in any paper to bring together all the known facts of science with a view to constructing some workable theory. The picture was so grey that no feature was recognisable, and they might as well be perfectly frank in making happy guesses, killing them off when they did not stand the test of fact and retaining only those which served as working hypotheses. That was a very unscientific way of proceeding, but it was a thoroughly British one.

He had not made these remarks by way of criticism of the paper, which was a very serious and valuable contribution, and would be referred to in years to come, but he had made them with a view of suggesting that those who took part in the discussion should follow the argument along these lines rather than attempt to survey the entire field.

Prof. V. C. Illing agreed with the President that the author in trying to cover such a vast field had perhaps failed to bring out into relief the essential differences between conflicting theories, but he suggested that the paper had this definite merit, that it attempted to reconstruct a definite story of the origin of oil instead of reserving its attention to only one limited point of view. The literature on the subject is enormous—most of it is utterly beside the point. The author instead of following well-beaten paths and discussing in detail the relative chances of particular types of organic life having been the important fundamental matter, had directed attention to the much more important question of the environment of deposition. If the question of the origin of oil was to be of use to scientists in the search for new oilfields, the speaker could think of no better viewpoint from which to study it than its relationship to the conditions of deposition. The particular organism was unessential—what was of importance was the conditions which would lead to the change of certain essentials in the organism —fatty bodies perhaps—into hydrocarbons.

Many theories of oil origin ended with the choice of the organic material—but this was really only the beginning of the story. The alteration of the material—how it altered and when it altered—was of primary importance, to reach an intelligent conception of the whole process. The speaker had been developing researches for the last three years *re* the point of view of the migration of oil, because he was convinced that until we knew more about the movements of oil through strata we were handicapped in our study of oil origin. The results of these researches made it difficult to account for oil migration except on the theory of a compacting sediment. This presupposes the oil, and therefore demands a theory of oil origin pene-contemporaneous with the sediments, and not as the distillation theory would suppose as a later process of metamorphism. For this among other reasons the speaker was more inclined to favour the bacteriological theory of oil formation.

With regard to the environment of oil formation, the speaker would like to contribute just one case of field evidence. The Island of Trinidad has given rise to many conflicting statements about the origin of petroleum, and he would like to add his to the quota. Although it had been asserted that there was abundant evidence in the island of close association between oil and lignitic material, the evidence, in the opinion of the speaker, would not bear close investigation. The main oil-bearing formations underlie the upper lignitic series, they are essentially marine and do not contain evidence of any important inclusion of terrestrial plant remains. On the other hand, they do contain foraminifera often in great abundance, and in the case of one horizon in the Pre-Marl series

the speaker had noticed a close relationship between the occurrence of petroleum and the evidence of included foraminifera. Towards the north of the Naparima region when these clays became gradually non-foraminiferal, a single horizon retained its organic content, and it was noticeable that this horizon, a stiff blue foraminiferal clay within a series of sterile clays, always contained petroleum; whereas the overlying and underlying clays gave no evidence of any saturation whatsoever. The writer did not wish to stress the foraminifera, but rather the conditions of deposition. The foraminifera it seemed to him might be replaced by other types of organic life . . . but the conditions of deposition were essentially in this case marine. They were the conditions of the intermixture of a clay sediment with organic material in relatively quiescent waters—leading to the envelopment of the organic matter in a muddy matrix on the floor of the sea and a decomposition of the organic material along other lines than the usual oxidation processes in shallow waters.

Mr. T. Dewhurst said that he could not refrain from expressing a little surprise at the President's criticism. A review of the various hypotheses that had been put forward to account for the origin of oil provided a good illustration of the chaos that could result from the habit of making guesses. This was because on the subject under review most of them had been unhappy guesses. If we could carry out our researches by an orderly, logical and scientific method, such as the President appeared to decry, it might lead to a frame of mind whereby at least the most unfortunate guesses would be avoided, and perhaps even one or two happy guesses made. He had the pleasure of listening to Mr. Clark's paper when it was first given to the Students' Section. The paper had not then been selected for the Students' Medal and Prize, and Members of Council were free to criticise the paper, and a long and interesting discussion took place. The author on that occasion emphasised the distillation hypothesis, and as he (the speaker) opposed this view strongly at the time, he therefore appreciated the excellent criticism of the distillation hypothesis in the paper as now presented. He found that he was unable to criticise the paper in its present form because he was in complete agreement with it. He would, however, draw the attention of Members to the very great unconformity which existed between this paper and much earlier papers, on the same subject. It was very satisfactory to record that such comparison showed quite clearly that great progress had been made, and was being made, in the evolution of our knowledge respecting the origin of oil, which was a subject of fundamental importance.

Mr. J. E. Hackford said that in view of the President's suggestions with regard to criticism, he must confine himself to facts so

far as he had observed them. The point Mr. Dewhurst had brought forward with regard to the distillation theory was one on which he would like to say a few words. The United States Bureau of Mines sent him many samples of the oils and rocks from Wyoming, as he held the position of umpire on certain matters. In his paper Mr. Clark had touched incidentally upon lateral and vertical migration of oil, a matter which came largely into view in the district around the "Teapot Dome." That was a formation in which the oldest and the newest forms of rocks were of oil-bearing strata, and there were five distinct beds from which oil was obtained. The peculiarity was, however, that every one of those beds, from the oldest to the newest, contained exactly the same oil with just a few variations in gravity due to local geological conditions. They were here confronted with a field containing five different beds of oil of different ages, all containing the same oil. How did it get there? The lowest horizon was a very big shale bed which stretched for many miles. Some of the shale was placed in a distillation flask placed in water at 100° C. or thereabouts, where the material was kept for nine months on end under sealed conditions. At the end of that time 5 c.c. of distillate was collected. He then indicated that to the side of the horizons was an igneous formation, and said that it was his opinion that the migration might be explained by the igneous intrusion and also that distillation might take a part in the process.

The first part of Mr. Clark's paper, which appeared to him very ably put together, was likely to appeal rather to workers on the geological side than to himself, because it contained a statement of the conditions under which the necessary deposition could take place. The question of the procedure of decomposition after the material had been deposited was, of course, one of the points of paramount importance. None of them knew really what the next step was after the production of methane—whether the breaking away of methane from such a body as a fatty ester with the elimination of paraffin produced the effects observed. There was not enough evidence on that point, but there was evidence that methane was produced by the decomposition of oil, and under violent reactions could be obtained upon decomposition. For instance, when oil was subjected immediately to a temperature of 3000° C. or 4000° C. methane hydrogen were produced almost exclusively.

The speaker went on to say that assuming the oil was formed by the decomposition of marine or vegetable matter, the question remained as to how it was that in one case oil was obtained and in another case coal. He did not wish to emphasise the point which had been brought out in one of the previous discussions. If terrestrial vegetation supplied the oily matter, then cellulose (which

was absent in the algæ) formed a sponge which held the oil up sufficiently long for it to be converted into a bitumen. The next point was, if asphaltenes, were put on a plate or in a vacuum tube at 110° C. or 113° C. and left there for nine months, they became insoluble in carbon bisulphide and ultimately one came to a phase where the whole of them became insoluble in pyridine. The matter that was insoluble in pyridine no longer had a melting point, and on heating gave off the same amount of gas, relatively speaking, as did anthracite on destruction distillation. He rather fancied that the question of prolonged heating caused the change-over from the soluble form of oil to the insoluble variety of bitumen found in the cellulosic matrix of coal.

Mr. A. Beeby-Thompson said that he had not intended, until the President called upon him, to take part in the discussion, but he would like to say that he really believed that the solution of the problem of oil origin would be found by closely studying present-day phenomena. Recently he had had occasion to investigate some interesting developments amidst deltaic conditions bearing on the problem. Within the last two or three weeks he was taken by a representative of the Greek Government to a spot in the Vardar delta, near Salonika, where wells were being drilled for water, and at a depth of about 40 metres a stratum had been struck in all wells which yielded a certain amount of gas, methane obviously. In one particular well the gas was discharged in large volumes under pressure, together with water and mud—in fact, for about a month before he reached the place the well had been in continuous eruption, resembling an oilfield bore. On ignition the gas burnt with a non-luminous flame about 10 ft. long. The delta deposits of the Vardar and associated rivers are very extensive and deep and why this particular bed amidst so many others should yield gas raised the very interesting question of suitable environment of a mother substance. Curiously, the well at occasional intervals stopped flowing, when the pressure built up and was followed by the violent ejection of enormous numbers of shells. The clay exhibited many of those peculiar features which one associates with oil strata. It was of a blue colour, very fine, micaceous or sericitic, slightly sandy, and had many of the curious characteristics found in the clays of oil measures. He had brought back samples which he hoped to get examined thoroughly and from which he trusted useful information bearing on the origin of the hydrocarbons might be forthcoming. While he was in this region a man volunteered the information that in another well, some years before, a black substance with oily odour had been struck, evidently bitumen from his description, at about the same depth, showing that there was a horizon which produced

gas and possibly other petroliferous substances, evidently due to some peculiar and critical conditions. The gas was unlikely to have economic value because the beds were horizontal and there could be no concentration, especially at a depth of only 40 metres. Much the same thing was observed in the littoral deposits of British Guiana, where, during drilling, a certain horizon distinctly petroliferous in character was passed at about the same depth in many wells. Near the Venezuelan boundary considerable attention had been attracted to a region where a typical bitumen oozed from the same littoral beds. As the sedimentaries were only a few hundred feet thick and were underlaid by igneous rocks, the bitumen can only have been derived from the sedimentaries. If fuller information was collected and recorded by oilfield engineers during the drilling of wells much useful data bearing on the origin of oil might be obtained. The abundance of iron pyrites in the dark days of oil measures must be associated with some form of decomposition phenomena.

He had been very much interested in Mr. Hackford's remarks with regard to the origin of oil in the "Teapot Dome," Wyoming, and in his suggestion of distillation from shales by an intrusion of igneous rocks. But he was under the impression that there were no igneous intrusions within many miles of the Salt Creek field. It was difficult to imagine how oil on this scale could have been produced by distillation of shales by intrusions, and few American geologists would accept this theory. He wished to express his appreciation with regard to the paper which must have entailed an enormous amount of labour. No unprejudiced person could fail to agree with a great deal that the author had written.

Mr. E. Clark said that the President had very justifiably criticised his (the author's) failure to bring into strong relief the outstanding features of the problem, a failure which resulted from attempting a complete survey in such a short paper. There was a confusion of theories concerning oil origin, and his object had been to co-ordinate existing ideas and to emphasise the fact that one is not dealing with single theories, or partial truths, but with a mosaic of theories, each of which grades into its neighbours and bears a definite relation to them. In one field the oil may have originated in one way, and in another in quite a different way as the result of mutual variation among the conditions governing origin.

The author greatly appreciated the remarks of Prof. Illing, and was gratified to learn that the unusual manner of approach to the subject met with his approval.

He also desired to thank Mr. Dewhurst for the generous terms in which he had referred to the paper.

Mr. Hackford had mentioned the distillation of oil from shales by igneous intrusions; the author, while admitting the possibility, thought that such action was rather of the nature of a geological accident. He had no knowledge of igneous intrusions closely associated with the "Teapot Dome" area.

MR. HACKFORD, interposing: The igneous rock was 150 miles away, but it held all the way through.

Mr. Clark thought that implied rather extensive migration, requiring exceptionally favourable geological conditions.

The examples described by Mr. Beeby-Thompson gave further confirmation of the intimate association of gaseous and even heavy hydrocarbons with recent deltaic deposits. The author supposed that the reason for the attention paid to deltaic formations was to be found in their accessibility, and he thought that if other deposits were examined, say up to 100 fathoms about the continental shelves, some interesting results might be obtained.

The President said that the outstanding point was the contrast between the knowledge of oil conditions now and the knowledge of them which obtained fifteen or twenty years ago. If that comparison were made the very real progress which had taken place in the meantime was evident. A very definite step forward had been taken in establishing the essential data and clearing out from consideration matter which was of no use to anybody. In that way the foundations had been laid—somebody's happy guess as to the origin of oil.

A vote of thanks to the author was accorded by acclamation, and the meeting terminated.

The following contribution was subsequently received from **Dr. Percy E. Spielmann**:

Mr. Clark's attitude towards his subject is that of a geologist demanding chemical help in the solution of his problems and, as such, he has, I think, been a little narrow in his "chief avenues of research," as much pure chemical and bacteriological work must be done in addition to that which "would probably be outlined" from the physiological and geological investigation that are immediately necessary.

I am in whole-hearted agreement with him when he calls for collaboration of the various sciences to elucidate this most difficult problem of the origin of petroleum. I have urged this more than once, so that, perhaps, when a few more such demands have been made, something may be done, sometime.

As Mr. Clark has quoted me as being the source of a suggestion that relates oil and coal to one another, I would point out that the idea put forward was not my own, as is shown by the two

bibliography numbers at the end of the sentence to which he refers.

In reply to Dr. Spielmann's remarks, the author is in complete agreement that there is a great deal of chemical and bacteriological research bearing on the subject of oil origin which could be immediately undertaken with great profit. In his opinion, however, a more definite knowledge of the conditions of oil origin would be most desirable, as defining the issues with greater clearness. This would facilitate the intelligent projection of research, a factor almost of equal importance to its prosecution.

A more exact knowledge of the permissible temperature and time conditions would be very useful, and the extent and nature of bacterial participation—the crux of the whole problem—would possibly become a matter of fact rather than conjecture.

There is again a strong probability that much of the organic and inorganic material of the environment of oil origin is in a colloidal state, another important factor of which little is known. The author did not intend to infer that the production of coal and oil from similar materials represented Dr. Spielmann's opinion; the reference was given advisedly because on the same page related facts were presented and discussed and further references given.

The Physical and Chemical Properties of Paraffin Wax, particularly in the Solid State.

By J. A. Carpenter, M.A., A.I.C.

Though the fractionation of waxes and the determination of a few constants have received some attention in the past, very little work has been published on the physical nature of solid mineral waxes. However, certain refining problems such as the mottling of candles, the behaviour of wax on standing, the cooling and pressing of heavy oil and paraffin distillate and the influence thereon of the crystalline condition of the wax, together with its behaviour on sweating, led to the study of the various conditions of crystalline stability of partially and completely fractionated waxes.

The present work is not completed, but, as far as it has progressed, shows some results of interest, which are grouped as follows :—

I. Fractionation, molecular weights and melting points of waxes from Burmah petroleum, with reference to the work of others.
II. The properties of a very high melting point mineral wax from the Singu Field in Burmah.
III. Observations on the cooling, expansion and microscopic properties of wax in mass.
IV. The crystallisation of wax from solvents.
V. The quantitative correlation of (3) and (4) in relation to transition of crystalline forms and physical constants.
VI. The effect of air and oil on the properties of waxes with regard to mottling, consistency, toughness and colour reversion, quantitative measurements and a "breaking point" test.
VII. The relation between amorphous and crystalline waxes.

The greater portion of the work has been done on Burmah mineral wax, but the properties of waxes from Assam, the Dutch East Indies and America have also been studied as far as is necessary to show that similar results are obtainable from all of them. Oxidation and further purely chemical research will not be given in this paper.

I. Fractionation, Molecular Weights, etc.

This part of the work has been discussed in the papers noted below, and has only as yet been followed out here as far as the matter in the following table and comments. (See Table p. 291.)

The fractionations were carried out by means of:—

Recrystallisation of refined high and low melting point Burmah waxes from petroleum spirit, chloroform, benzol, carbon tetrachloride, etc.

Fractional cooling of solutions in oil.

Fractional distillations and sweatings.

Ultimately, in order to work towards definite chemical compounds as far as possible, recrystallisations were carried out repeatedly, but the quantity of any definite compound present in the wax was difficult to estimate on this account.

On the whole, as the properties of these wax components are additive with regard to average melting points and average molecular weights, also as the properties merge so gradually when a series is ascended or descended, it is difficult to be sure at any time that one is dealing with a definitely pure compound. However, the work of Wilson[1] and the author are interconfirmatory in many ways, though more "halting points," giving molecular weight determinations close to formula requirements, have been obtained in the present work.

The molecular weight determinations were carried out by the ebulliscopic method of Beckmann, using benzene, chloroform or carbon tetrachloride as solvent; they gave fairly consistent results though difficulty was sometimes experienced. Cryoscopic methods with waxes were soon abandoned as an unsatisfactory method.

From the results it is reasonable to suppose that most, if not all, of the hydrocarbons from $C_{21}H_{44}$ up to $C_{34}H_{70}$ are present in wax obtained from Burmah crude petroleum as it reaches the refineries through the pipe line, while a few higher compounds, particularly one with a melting point of 96·5° C. and a formula approximating $C_{57}H_{116}$, are present in Sucker Rod wax on the Singu field and deposited in pipe lines leaving that field.

The range in refinery crude wax appears to be moderately evenly distributed, and the chief constituents, which appear more well defined than the others, are those with melting points near 41° C., 44–5° C., 47–8° C., 52–3° C., 57–8° C., 61–3° C., 66–7° C. and a very definite, though smaller, quantity at 71–2° C.

The work has not yet been carried out as fully as is desirable, and further fractionations by vacuum distillation followed by re-

[1] W. J. Wilson, *Journ. Inst. Petr. Techn.* **10**, p. 236 (1924).

crystallisation are in progress, but on looking at the table of comparisons given here, some anomalies are obvious and give results similar to those described by Francis[2] and his assistants in their work on Scotch shale wax.

It is noticed that succeeding fractions crystallising from a solvent often have identical and sharp melting points, but give different molecular weights and, conversely, bodies with similar molecular weights at times give different melting points. In the case of 66·5° C. and 70° C. waxes, the molecular weights are even reversed although determinations give results within 2 per cent.

This suggests the possibility of the presence of isomers of the normal hydrocarbons, or even of saturated naphthenes of general formula C_nH_{2n}, particularly among the higher bodies present.

The data for such naphthene and paraffin bodies obtained by combustion or molecular weight determinations are sufficiently near to one another to fall within the limits of experimental error, especially owing to the possibility of imperfect fractionation, but it is hoped to extend the work to optical investigations.

Since the above work was done, papers have been published by Müller and Savile[3] and by Piper, Brown and Dyment,[4] on the application of X-rays to the study of hydrocarbon molecules. The latter group of workers, by obtaining "spacing" photographs, confirm Francis'[2] observations on seven shale wax fractions and conclude that they are almost pure normal hydrocarbons; they also clear up some of Francis' anomalous molecular weight values by adopting the method of Menzies and Wright.[5] These methods, when applied to Burmah fractions, should give interesting results, and should shed some light on the presence or otherwise of isomers, higher saturated naphthenes, or the less well defined intermediate members of the normal hydrocarbon series.

The following table summarises the present work and gives comparisons with the work of Wilson,[1] Francis,[2] Piper,[4] Mabery,[6] Rakusin.[7] Gascard,[8] Krafft[9] and Müller,[3] that of Rakusin, Gascard

---

[2] Francis, Pope and Coysh, *J. Chem. Soc.* **121**, p. 496 (1922). Francis, Watkins and Wallington, *J. Chem. Soc.* **121**, pp. 1529, 2804 (1922). Francis, Millard, Rutt, Watkins, Wallington and Garner, *J. Chem. Soc.* **125**, p. 357 (1924).

[3] Müller and Savile, *J. Chem. Soc.* **127**, p. 599 (1925).

[4] Piper, Brown and Dyment, *J. Chem. Soc.* **127**, p. 2194 (1925).

[5] Menzies and Wright, *Amer. Chem. J.* **43**, p. 2314 (1921).

[6] Mabery, *Proc. Amer. Acad.* **37**, p. 565 (1901–2); *Proc. Amer. Acad.* **40**, p. 349 (1904–5); *Amer. Chem. J.* **33**, p. 285 (1911).

[7] Rakusin, *Petroleum* **20**, p. 951 (1924); *J. Soc. Chem. Ind.* **43**, p. B702 (1924).

[8] Gascard, *Ann. Chim.* **15**, p. 332 (1921); *Chem. Abstr.* **16**, p. 48 (1922).

[9] Krafft, *Ber.* **40**, p. 4783 (1907).

and Müller being mainly on synthetic normal paraffin hydrocarbons.

The first three columns represent present work on Burmah wax, the next, Wilson's work on similar wax, and the others, data from other sources.

COMPARATIVE TABLE OF ANALYSES (Temperatures Centigrade).

Melting pt. of fractions.	Mol. wt. found.	Nearest mol. formula.	Wilson's[1] fractions.	Francis[2] M. pt.	Francis[2] Mol. wt.	Synthetic and other data. Melting pt.	Synthetic and other data. formula.	Reference.
41	295—298	$C_{21}H_{44}$	—	37—38	291	40·4—41	$C_{21}H_{44}$	(3) (7)
44—45	313	$C_{22}H_{46}$	—	44·0	325 (321)†	44·4	$C_{22}H_{46}$	(7)
47—48	320—324	$C_{23}H_{48}$	47—48	—	—	47—47·7	$C_{23}H_{48}$	(3) (7)
—	—	—	—	—	—	48·0	$C_{24}H_{50}$	(6)
52·2	338—341	$C_{24}H_{50}$	—	51·9	332 (338)†	51·1	$C_{24}H_{50}$	(3) (7)
—	—	—	53·6	53·2	358 (368)†	53·0	$C_{25}H_{52}$	(6)
57·2	380—384	$C_{27}H_{56}$	57·3	57·3	394 (366–9)†	56·0	$C_{26}H_{54}$	(8)
57·9	398	$C_{28}H_{58}$	—	—	—	—	—	—
60·0	—	—	—	—	—	59·5	$C_{27}H_{56}$	(3) (7) (8)
61·5	405—410	$C_{29}H_{60}$	61·5	60·9	419 (390–6)†	—	—	—
63—64	421—426	$C_{30}H_{62}$	64·2	63·3	449 (407–10)†	< 64·0	$C_{28}H_{58}$	(9)
66·5	462—464	$C_{32}H_{66}$	—	66·6	434 (443)†	66·0	$C_{29}H_{60}$	(8)
—	—	—	68·8	—	—	68—69	$C_{31}H_{64}$	(3) (7) (8) (9)
70·0	450	$C_{32}H_{66}$	—	69—72	528	70—70·5	$C_{32}H_{66}$	(7) (8)
	(in CCl_4)				(in CS_2)	71·8	$C_{33}H_{68}$	(9)
71·7	468—474	$C_{33}H_{68}$	71·7	—	—	71—72	$C_{34}H_{70}$	(6)
		or $C_{34}H_{70}$				73·2	$C_{36}H_{74}$	(8)
—	—	—	—	—	—	74—74·7	$C_{36}H_{72}$	(3) (7)
*76—79						76·0	$C_{38}H_{78}$	(7) (8)
*84—85	Those have not been prepared as well defined compounds.							
*91—92								
*96·5	Over 800	abt. $C_{72}H_{146}$				95·0	$C_{46}H_{118}$	(8)
						100·5	$C_{50}H_{102}$	(8)
						102·0	$C_{54}H_{110}$	(8)

* Fields, pipe line, or B.S. wax only. † M. wts. given in ref. (4).

II. Very High Melting Point Waxes.

Though 71·7° C. M.Pt. wax is the highest obtainable from clean Burmah crude after passage through its 300 mile pipe line, higher fractions have been sometimes obtained from bottom settlings taken from old crude oil storage tanks. Those from some tanks have given waxes with melting points up to 84–85° C., and from other tanks up to 76–79° C. on repeated refractionations. Larger quantities of these probably exist in Fields Stock Tank B.S. and Pipe Line Stations.

These waxes are comparatively insoluble in solvents, but are nevertheless difficult to purify to constant values. They are all saturated hydrocarbons of a crystalline nature, crystallising from solvents in rhomboid plates.

What is believed to be the highest-melting pure hydrocarbon mineral wax ever described is found on the Singu Field of Upper Burmah in Sucker rod paraffin, also in the material around the rigs and obtainable from pipe lines locally when the latter are steamed.

As it occurs, it is generally in the form of an intimately mixed colloidal mass of mud, asphalt and wax of a dark red-brown colour, melting at 87–88° C.

The best way to refine this crude wax is to melt and settle over hot water with centrifugal treatment if possible. The layer is then cooled and sweated, the first 5 per cent. of oily material and the last 5 per cent. of asphaltic solids being rejected, and the middle 90 per cent. cut filtered through bauxite. Alternatively, the raw crude material may be extracted with petrol and filtered through Fuller's earth or bauxite, and the latter washed through with pure petrol at the end of the operation.

By either of the above or other alternative methods, the wax is obtained as a slightly yellow opaque solid of crystalline structure, tough, rather insoluble in solvents, and of melting point 88–91° C.

On recrystallising from petroleum spirits, benzol or chloroform, small white plate-like crystalline masses are obtained, fractionating to 91–96° C. and refractionating to a maximum of 96·5° C. after repeated trials, the mother liquor retaining some oily and amorphous material.

This wax of M.Pt. 96·5° C. or 205·7° F. is a white opaque, but crystalline body; it is very sparingly soluble in organic solvents and possesses a hard though somewhat brittle consistency when in mass at ordinary temperatures. It is a pure hydrocarbon giving on combustion C. 85·3, H. 14·8, *M*, Ebulliscopic in Carbon Tetrachloride, 805. ($C_{57}H_{116}$ requires C. 85·5, H. 14·5 per cent.; *M*, 800.)

It is free from unsaturation, acid value, saponification value or oxygen, and when mixed with ordinary waxes, imparts hardness and opacity with freedom from mottling; it plays the part in these respects of five to ten times its own weight of stearin. Density and expansion are noted below. Unfortunately, the supply of this wax even in the crude state is exceedingly limited.

The intermediate hydrocarbons between $C_{37}H_{116}$ and $C_{34}H_{70}$ have not been identified with certainty, and apparently only very small quantities are present.

Further work remains to be done on the solubilities of these waxes in solvents, but, with a given solvent, the curve of increasing solubility with descreasing molecular weight is quite regular.

III. Observations on the Cooling, Expansion and Microscopic Properties of Waxes in Mass.

General.—The successful treatment of wax-containing distillates for the production of finished white waxes in a refinery is obviously dependent on the correlation of efficient methods with the crystalline properties of wax in mass or cooling from solutions in oil. Though general technique connected with the regulation of cooling, pressing, sweating and filtration has been a matter of experience for years, many of the underlying physical properties of crystalline wax seem to have received very little attention.

The present studies of cooling at different rates and ranges of temperature show that there are certain transition points from one crystalline form (needles), stable down to about 10–15° C. below the melting or crystallisation point of a mixture, to another form (leafy plates or laminated masses), stable at lower temperatures, and possibly even another transition point at still lower temperatures.

Rapid cooling into the range of stability of leafy plates is not as effective as initial slow cooling to seed out the mass with needles followed by rapid cooling after that, and this is not simply a function of the fact that rapid cooling produces smaller crystals than slow cooling, for the phase as well as the crystal size comes into effect.

Cooling in shallow glass vessels.—When a pure wax fraction, or even a finished refinery cut, is melted in a clock-glass and cooled, it is noticed that:—

1. On initial setting, needle-like formations are seen at the edges of the liquid.
2. The mass after initial plasticity becomes opaque over a range of 5–10° C. below the melting point, with a dull surface.

3. The mass then becomes translucent again.

This occurs from 10–15° C. below the melting point; at the same time the surface becomes shiny, crystals obviously "pack up" considerably, and small flowery patches of air may separate at crystal edge nuclei in the mass (the phenomenon of "mottling").

On reheating, air bubbles are expelled from the "mottles," and this mottling is apparently a function of air solubility and of inequality of contraction connected with the crystallisation of the wax; it is increased by the presence of oil in the wax. In fact, if a drop of oil be added carefully, the immediate region of that drop becomes excessively mottled.

When the above experiments in (1), (2) and (3) are done in a clock glass where the depth increases towards the centre, the greater rapidity of cooling at the outer edges produces the striking effect of concentric rings of "effect" drawing gradually in to the centre.

Again, when a cold mass of wax is heated, separation of air increases up to some point; when molten wax is being cooled, mottles begin to appear at practically the same point; this suggests a minimum solubility of air at the temperature of translucency, some 10–15° C. below the melting point.

Another noticeable point is that, if the surface be cooled quickly while there is liquid below it, a distinct positive ridge develops a little way in from the edge as the plastic stage is passed.

This suggests irregularity of contraction at different ranges in the solid phase, otherwise the surface would be regularly concave towards the middle; all these observations are borne out by the quantitative tests described below.

Observations under the microscope.—When a pure wax cools slowly from the liquid state, it appears at first to yield needles. If mother liquor be poured off from a partially solidified mass, this is very evident, and the main formation is that of radial masses of elongated prisms, sometimes with pointed ends and sometimes rounded. As any mass cools, needles may be seen to cross and recross, but presently pack down tightly into transparent masses of a laminated form.

More rapid cooling with ice shows obviously large strains taking place, resulting in cracks and the formation of distorted plates between the cracks.

The mass usually assumes an amorphous appearance under the microscope under these conditions.

IV. (*a*) Crystallisation from Solvents.

Observations under the microscope were taken on the crystallisation of various recrystallised fractions and refinery wax cuts from light and heavy mineral oils (petroleum ether up to heavy lubricating oils), acetone, ether, chloroform, benzol, toluol, glacial acetic acid, carbon tetrachloride and other organic solvents. All methods were employed, including evaporation at high and low temperatures, rapidly, slowly and in stages; also standing to allow evaporation of the solvent to take place in the cold, in thermostats and in currents of air.

The general results of several hundred observations are as follows:—

Slow cooling from high-boiling solvents gives large prismatic needles, sometimes blunt-ended, sometimes truncated, at others pointed, and at times in the case of lower fractions, capped with a bullet-nose shaped series of caps, superimposed on one another.

Long acicular prisms lie loosely on one another, crossing and recrossing as the solvent becomes saturated, and these needles are best in shape when the purer recrystallised fractions (especially of M.Pts. 71·7° C., 66·5° C., 61·5° C., 57·9° C., 52·2° C. and 44·5° C., see Table p. 291) are employed. On standing, these needles pack together, though they still retain their general shape to some extent.

Slow cooling from low-boiling solvents gives crystals depending in character on the actual temperature and on the wax employed.

At all times within 15–20° C. of the melting point of the wax, needles are obtained, the size varying inversely with the rate of cooling.

Below this temperature range the higher waxes give flat rhomboid plates or foliaceous masses often super-imposed on one another (*e.g.*, petroleum-ether solutions of the three higher waxes, allowed to evaporate at ordinary temperatures and lower).

The crystals sometimes have rounded angles, but the perfect form is that of a rhomboid plate with angles of 120° and 60°, such that the short diagonal divides the area into two equilateral triangles.

The 44·5° C. fraction, however, at ordinary temperatures of about 30° C. gives beautiful crystals of an acicular nature resembling rockets and rifle bullets in shape, often radiating out in groups of three from a common centre. The ends are often capped with two or three parabolic caps, and there is a longitudinal line visible along each needle such that the cross section of that needle shows a cusp.

At times the formations appear as a ring of three such crystals end to end in the form of an equilateral triangle.

With somewhat more rapid cooling, distorted needles of worm-like forms are produced, but at lower temperatures the leafy crystals and laminated masses are in evidence.

Rapid cooling to ordinary and lower temperatures from high-boiling solvents gives small crystals, and needles are difficult to find, as the general form is that of plates, but initial rapid crystallisation from a hot concentrated solution, as it falls through intermediate ranges, produces interlacing distorted worm-shaped formations.

Rapid cooling from low-boiling solvents, with the exception noted above for 44.5° C. wax, nearly always produces transparent well-packed masses with irregular edges and composed of small foliaceous forms.

The recrystallised waxes of M.P. 66·5° C., 61·5° C. were used to demonstrate that either form of crystal could be changed to the other without change of molecular weight. Firstly, crystals were produced from ether at a low temperature and from glacial acetic acid at about 55° C. respectively. Foliaceous crystals from the first method and acicular crystals from the second method were dissolved in the reversed solvents and crystallised, giving the reversed phases for each wax. Molecular weights were determined from benzene in each case, but no change could be found.

IV. (*b*) Crystallisation from Mineral Oils.

This is one of the most important studies from the refiner's point of view, and the phenomena follow the ordinary laws holding good for inorganic solutions. The following observations, some of which embrace well-known technique in refining, were verified directly under the microscope :—

1. The more rapid the rate of cooling of a given heavy-oil-wax distillate mixture between given ranges, the smaller the crystals.
2. The more concentrated the solution of wax, the smaller the crystals. (This may be partially compensated for by the slower cooling produced by evolution of more latent heat.)
3. The more viscous the oil forming the mother liquor, the smaller and less well-defined are the crystals, *ceteris paribus*.

This was verified with a range of oil cuts varying from petroleum ether up to heavy lubricating oil.

From this it follows that, if good wax is to be obtained from a very high distillate fraction, it may be necessary to cut back the fraction with a light oil before cooling and pressing.

4. Taking a high melting point wax in the foliaceous phase and a lower melting wax in the acicular phase through the same temperature range (in which each respectively is the

stable form), and crystallising them out at the same rate from a light oil fraction, the wax in the acicular phase gives far better crystal masses more easily freed from oil than the other phase.

From a variety of observations, it always seems to hold good that the needle-shaped crystals lie far more loosely on one another in an open network than foliaceous masses when mother liquor is still present, so that pressing the former kind free from oil is much the easier proposition. It is admittedly difficult to make fair comparisons for the same wax under similar conditions, and it is accordingly difficult to say exactly how far in proportion the production of smaller crystals by rapid cooling, apart from the presence of one or other crystalline phase, affects the ease of pressing, but that the phase has an appreciable influence is certain.

5. Cooling in stages, slowly for the first stage and rapidly afterwards, still gives good crystals. This is intimately bound up with observation (4) above, and supports the views expressed. Even if acicular crystals change internally below a certain temperature range, they still lie loosely in their original shapes and allow for the easy expression of oil. Also further crystals will use them as nuclei.

6. The advantage of slow cooling in a preliminary high temperature stage is also evident from observations (2) and (3), owing (*a*) to better distribution of amounts separating, therefore giving rise to the *effect* of lower concentration in the mother liquor and less supersaturation; also (*b*) to the lower viscosity of the oil at the upper temperature stage, allowing good crystals of the higher melting point waxes to separate in the acicular phase before the oil gets too viscous, and before the lag compels most of the higher waxes to come down in the foliaceous phase out of the more viscous oil with the formation of small oil-occluding crystals or masses.

7. Dirt in mechanical suspension other than in colloidal form has little or no effect on crystallisation.

8. Asphaltic material, resins, amorphous mineral jelly or colloidal mud are all definitely harmful both to the size and definition of separating crystals.

Mineral jelly or amorphous "wax" is not of the same type of chemical composition as a true wax; the former is practically a high flow point lubricant of an unsaturated character, and is more soluble in liquid fractions and less volatile than true paraffins.

However these jellies, when liquid, dissolve wax into true solution, and render good crystallisation almost impossible when they are present in appreciable quantities.

9. In the case of a second cooling for a soft scale, the nature of the crystals is conserved by the fact that heat transference is necessarily restricted both by the smaller differences in temperature and by the adherent nature of the non-conducting films of wax formed on all types of coolers, in addition to the fact that, for many of the lower waxes still present, the range of temperature is at first in the stability zone for acicular crystals.

10. Low melting waxes tend to retain more oil, and are plastic to the touch.

However, these plastic waxes crystallise extremely well from light solvent, and are utterly different from the amorphous "waxes" or jellies present in heavy residues, or even at times dissolved in lubricating oil fractions which have not been sufficiently cold-settled.

Crystals forming at higher temperatures in the cooling of heavy oil and wax distillates from Burmah petroleum are very well defined and frequently appear under the microscope in the form of rectangular crosses, the arms of which are sharp prismatic needles. The same has been noticed with corresponding fractions of many other crudes examined.

Some of the observations in (3), (5) and (8) above are similar to those reported by Bergel[7] and Fuchs,[8] particularly regarding the presence of asphalt or other colloidal matter.

When refining a mixed asphaltic paraffin crude, it is therefore advisable to separate the asphalt at as early a stage as possible and get rid of the worst of it before the oil-wax distillate pressing stage, as not only is the crystallisation affected, but the co-precipitation of asphalt renders the production of a pure wax by subsequent sweating and filtration more difficult. This also confirms the observations of Mr. H. L. Allan, of the Burmah Oil Co., who recognised the fact some time ago and put its application into effect in large scale plants with success.

V. Determination of Solubility, Expansion, Density and Transition Points.

Attempts to fix transition points were made by the following methods:—

(1) Thermometric methods.

(2) Solubility in solvents.

[7] Bergel, *Petroleum* **14**, 173 (1919); *Chem. Abstr.* **14**, 3787 (1920).

[8] Fuchs, *Petroleum* **14**, 1281 (1919); *Chem. Abstr.* **14**, 3787 (1920).

(3) Expansion and density.

(4) Air solubility in wax.

1. *Thermometric method.*—This method failed to give reliable results. Non-conductivity of wax, combined with inability to stir in the solid state, upset any attempt to measure accurately any change in the rate of cooling or heating.

2. *Solubility in solvents.*—As yet very little quantitative work has been done here and a more detailed study is in hand. Such experiments as have been done show an inflexion in the curve of percentage solubility in solvents plotted against temperatures above and below the melting point of the wax.

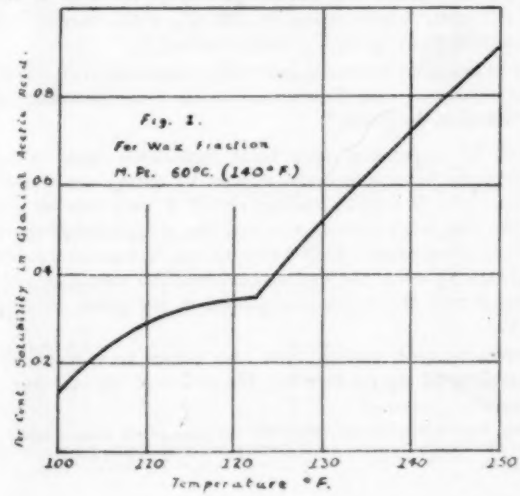
As an example, a refinery cut of M.P. 58° C. was once refractionated from benzol and a fraction of M.P. 60° C. was taken.

The solvent employed for the solubility test was glacial acetic acid with the following results :—

Temperature. ° F.	Solubility. %	Temperature. ° F.	Solubility. %
150	0·91	122·5	0·35
140 (=m.pt.)	0·72	120	0·33
135	0·62	115	0·31
130	0·51	110	0·29
125	0·41	105	0·23
—	—	100	0·13

The curve (Fig. 1) shows a decided change in the neighbourhood of 122° F. or 50° C., while between 105° F. and 110° F. there is also a less well defined change in the solubility rate.

Compare the above with the expansion curves below.



3. *Expansion and density.*—These data were obtained for a variety of pure recrystallised waxes, as well as ordinary refinery-finished high and low melting point cuts, including other than Burmah products.

The measurement of absolute expansion from degree to degree must be carried out very slowly and at a rate not greater than 1° C. per 15 minutes owing to the non-conductivity of the solid wax and the thermometric lag thereby caused. Further, it is necessary to expel air previously by steam or by repeated heating and cooling, otherwise liberation from solution at critical points gives false values.

The methods employed were as follows:—

(*a*) A rough method for total expansion over a range from ordinary temperatures (30° C.) to above the melting point (as a check only).

A weighed quantity of melted wax was freed from air in a measuring cylinder and just allowed to solidify on its surface sufficiently to allow air free water to rest on top.

The whole was cooled to 30° C. and the reading of the water surface noted.

The whole was then warmed to the final temperatures, the volume of water and liquid wax then being noted, after allowing for the known expansion of water and vessel.

(*b*) Direct determinations of densities of liquid wax at 100° C., 70° C., and, where possible, 60° C., were carried out in pyknometers or specific gravity bottles.

Density in the solid state was generally calculated from expansion data combined with the above, but a few checks were obtained by flotation methods.*

(*c*) Rates of expansion and total expansion were measured accurately from degree to degree by filling the upper half of one side of a pyknometer, or of a test tube drawn out at the end, with air-free wax and the remainder of the vessel with air-free water. This water was pushed along a calibrated capillary tube by the expansion after the wax-end had been stopped and the apparatus placed in the gradually-warmed bath.

The contraction on cooling was also taken to correct for any possibility of lag on melting, liberation of air or other error,

* Ordinary waxes containing dissolved air will often give slightly lower densities by the alcohol-water method than those obtained for air-free waxes in these tables.

and, apart from a slight temperature lag, was found in all cases to be the exact reverse of the expansion curve. All corrections for weight of air in weighing vessels, expansion of water and vessels, etc., were applied.

The results of the measurements are collected into the following tables and attached figures; they have been obtained from a few recrystallised fractions as well as from ordinary finished refinery cuts and mixtures, but the fractions are not quite the purest compounds used for molecular weight determinations owing to the small quantities of the latter so far obtained in this series of experiments.

Tables of Expansion and Density.

1. Refined Fields Wax, M.Pt. 90° C.

Range, ° C.	Condition.	Average coef. expansion per degree Cent. over range.	Cumulative % volume increase.	Density grams/c.c. at upper temp. limit.
0	Solid	—	0·0	0·9112
0—30	,,	0·0001	0·3	0·9086
30—40	,,	0·0003	0·6	0·9060
40—50	,,	0·0010	1·6	0·8970
50—60	,,	0·0013	2·9	0·8856
60—70	,,	0·0017	4·6	0·8712
70—75	,,	0·0021	5·7	0·8621
75—80	,,	0·0033	7·3	0·8484
80—85	,,	0·0055	10·0	0·8284
85—90	,,	0·0077	13·9	0·7999
90—91	Melting	0·0349	17·4	0·7760
91—100	Liquid	0·0010	18·3	0·7756

2. Recrystallised Fraction M.Pt. 65° C.

0	Solid	—	0·0	0·9256
0—30	,,	0·0010	3·0	0·8986
30—50	,,	0·0010	5·0	0·8815
50—52	,,	0·0015	5·3	0·8790
52—55	,,	0·0039	6·5	0·8691
55—56	,,	0·0090	7·4	0·8618
56—58	,,	0·0043	8·2	0·8554
58—61	,,	0·0028	9·1	0·8484
61—63	,,	0·0063	10·3	0·8390
63—65	,,	0·0097	12·3	0·8242
65—66	Melting	0·0570	18·0	0·7844
66—70	Liquid	0·0010	18·4	0·7815
70—100	,,	0·0010	21·4	0·7624

3. Recrystallised Fraction, M.Pt. 63·5° C.

Range, ° C.	Condition.	Average coef. expansion per degree Cent. over range.	Cumulative % volume increase.	Density grams/c.c. at upper temp. limit.
0	Solid	—	0·0	0·9430
0—30	,,	0·0010	3·0	0·9156
30—45	,,	0·0012	4·8	0·8999
45—50	,,	0·0032	6·4	0·8869
50—52	,,	0·0049	7·4	0·8780
52—55	,,	0·0052	8·9	0·8660
55—57	,,	0·0048	9·9	0·8580
57—60	,,	0·0024	10·6	0·8528
60—62	,,	0·0058	11·8	0·8435
62—63	,,	0·0155	13·3	0·8322
63—64	Melting	0·0760	20·9	0·7800
64—70	Liquid	0·0010	21·5	0·7760
70—100	,,	0·0010	24·5	0·7570

4. Recrystallised Fraction, M.Pt. 60·5° C.

0	Solid	—	0·0	0·9408
0—30	,,	0·0010	3·0	0·9135
30—40	,,	0·0010	4·0	0·9046
40—45	,,	0·0023	5·1	0·8951
45—50	,,	0·0061	8·2	0·8695
50—52	,,	0·0044	9·1	0·8624
52—55	,,	0·0018	9·6	0·8584
55—60	,,	0·0075	13·3	0·8302
60—61	Melting	0·0750	20·8	0·7790
61—70	Liquid	0·0010	21·7	0·7730
70—100	,,	0·0010	24·7	0·7550

5. Mixtures of Nos. 3 and 4, M.Pt. 62° C. (from 60·5° and 63·5° waxes).

0	Solid	—	0·0	0·9420
0—30	,,	0·0010	3·0	0·9148
30—40	,,	0·0011	4·3	0·9031
40—45	,,	0·0014	5·0	0·8972
45—47	,,	0·0016	5·3	0·8948
47—50	,,	0·0044	6·6	0·8838
50—52	,,	0·0075	8·1	0·8715
52—55	,,	0·0025	8·9	0·8652
55—58	,,	0·0018	9·4	0·8621
58—62	,,	0·0094	13·2	0·8320
62—63	Melting	0·0790	21·1	0·7779
63—70	Liquid	0·0011	21·8	0·7735
70—100	,,	0·0010	24·8	0·7540

6. An American Refined Wax, M.Pt. 56° C.

Range, ° C.	Condition.	Average coef. expansion per degree Cent. over range.	Cumulative % volume increase.	Density grams/c.c. at upper temp. limit.
0	Solid	—	0·0	0·9327
0—20	,,	0·0010	2·0	0·9145
20—30	,,	0·0013	3·3	0·9030
30—32	,,	0·0013	3·6	0·9005
32—35	,,	0·0027	4·4	0·8932
35—37	,,	0·0029	5·0	0·8882
37—40	,,	0·0042	6·3	0·8775
40—45	,,	0·0022	7·4	0·8684
45—50	,,	0·0020	8·4	0·8604
50—55	,,	0·0074	12·1	0·8320
55—57	Melting	0·0367	19·4	0·7810
57—60	Liquid	0·0009	19·7	0·7790
60—70	,,	0·0010	20·7	0·7726
70—100	,,	0·0010	23·7	0·7534

7. A Refinery Cut, M.Pt. 61·25° C.

0	Solid	—	0·0	0·9332
0—30	,,	0·0008	2·4	0·9115
30—40	,,	0·0011	3·5	0·9018
40—45	,,	0·0024	4·7	0·8912
45—47	,,	0·0024	5·2	0·8871
47—50	,,	0·0046	6·6	0·8755
50—55	,,	0·0022	7·7	0·8666
55—60	,,	0·0066	11·0	0·8408
60—62	Melting	0·0385	18·7	0·7862
62—70	Liquid	0·0009	19·4	0·7815
70—100	,,	0·0010	22·4	0·7627

8. A Refinery Cut, M.Pt. 59° C.

0	Solid	—	0·0	0·9360
0—30	,,	0·0010	3·0	0·9088
30—35	,,	0·0011	3·5	0·9045
35—40	,,	0·0025	4·8	0·8930
40—42	,,	0·0040	5·6	0·8867
42—43	,,	0·0052	6·1	0·8821
43—45	,,	0·0046	7·0	0·8748
45—47	,,	0·0036	7·7	0·8692
47—50	,,	0·0018	8·3	0·8644
50—55	,,	0·0023	9·4	0·8555
55—59	,,	0·0126	14·4	0·8182
59—60	Melting	0·0535	19·8	0·7822
60—70	Liquid	0·0010	20·8	0·7750
70—100	,,	0·0010	23·8	0·7561

9. A Recrystallised (once) Fraction, M.Pt. 44·5° C.

Range, ° C.	Condition.	Average coef. expansion per degree Cent. over range.	Cumulative % volume increase.	Density grams/c.c. at upper temp. limit.
0	Solid	—	0·0	0·9268
0—10	,,	0·0011	1·1	0·9168
10—15	,,	0·0014	1·8	0·9106
15—16	,,	0·0017	2·0	0·9087
16—20	,,	0·0051	4·0	0·8911
20—22	,,	0·0034	4·7	0·8852
22—26	,,	0·0018	5·4	0·8786
26—30	,,	0·0031	6·6	0·8695
30—33	,,	0·0016	7·1	0·8653
33—35	,,	0·0021	7·5	0·8622
35—37	,,	0·0045	8·4	0·8550
37—41	,,	0·0033	9·8	0·8441
41—44	,,	0·0120	13·4	0·8174
44—45	Melting	0·0519	18·5	0·7821
45—50	Liquid	0·0010	19·0	0·7790
50—60	,,	0·0010	20·0	0·7724
60—70	,,	0·0010	21·0	0·7652
70—100	,,	0·0010	24·0	0·7465

10. A Refinery Cut, M.Pt. 52° C.

0	Solid	—	0·0	0·9319
0—20	,,	0·0010	2·0	0·9235
20—25	,,	0·0015	2·7	0·9167
25—27	,,	0·0030	3·3	0·9118
27—30	,,	0·0030	4·2	0·9039
30—32	,,	0·0034	4·9	0·8978
32—35	,,	0·0046	6·3	0·8862
35—40	,,	0·0019	7·2	0·8787
40—45	,,	0·0022	8·3	0·8698
45—50	,,	0·0081	12·4	0·8382
50—52	,,	0·0110	14·6	0·8219
52—53	Melting	0·0554	20·1	0·7842
53—60	Liquid	0·0012	20·9	0·7790
60—70	,,	0·0010	21·9	0·7728
70—100	,,	0·0010	24·9	0·7541

11. A Refinery Cut, M.Pt. 60° C., and a Mixture (50—50) with No. 10 (M.Pt. 52° C.) of M.Pt. 56° C.

0	Solid	—	1·0	—	0·0
0—20	,,	0·0010	2·0	0·0010	2·0
20—30	,,	0·0010	3·0	0·0014	3·4
30—35	,,	0·0010	3·5	0·0021	4·4
35—38	,,	0·0010	3·8	0·0038	5·6
38—40	,,	0·0010	4·0	0·0028	6·2
40—43	,,	0·0023	4·7	0·0030	7·1
43—45	,,	0·0040	5·5	0·0017	7·4
45—47	,,	0·0062	6·7	0·0017	7·7
47—48	,,	0·0047	7·2	0·0017	7·9
48—50	,,	0·0028	7·8	0·0028	8·4

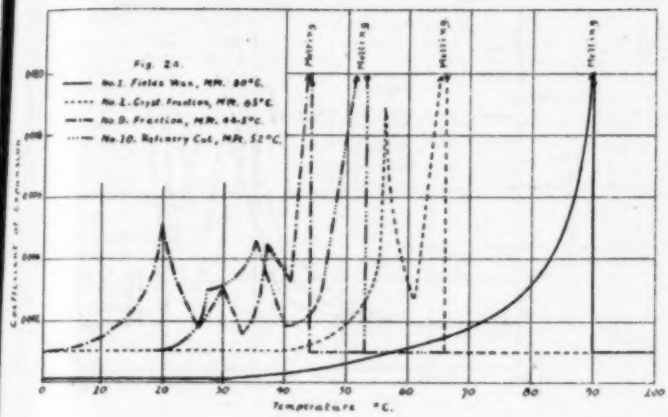


Fig. 20.
No. 1. Fields Wax, MPt. 50°C.
No. 2. Crystl. Fraction, MPt. 65°C.
No. 9. Fraction, MPt. 44-5°C.
No. 10. Refinery Cut, MPt. 52°C.
Melting
Melting
Melting
Melting
Coefficient of Expansion
Temperature °C.

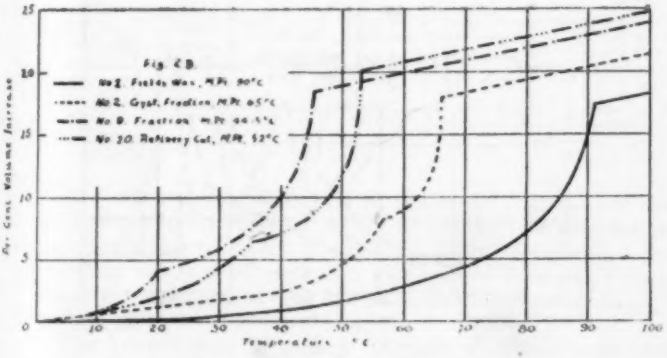


Fig. 21.
No 1. Fields Wax, MPt. 50°C
No 2. Crystl. Fraction, MPt. 65°C
No 9. Fraction, MPt. 44-5°C
No 10. Refinery Cut, MPt. 52°C
Per Cent Volume Increase
Temperature °C

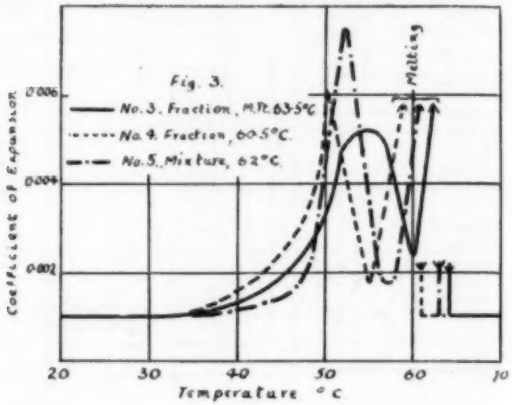


Fig. 3.
No. 3. Fraction, M.Pt. 63·5°C.
No. 4. Fraction, 60·5°C.
No. 5. Mixture, 62°C.
Melting
Coefficient of Expansion
0·006
0·004
0·002
20
30
40
50
60
70
Temperature °C.

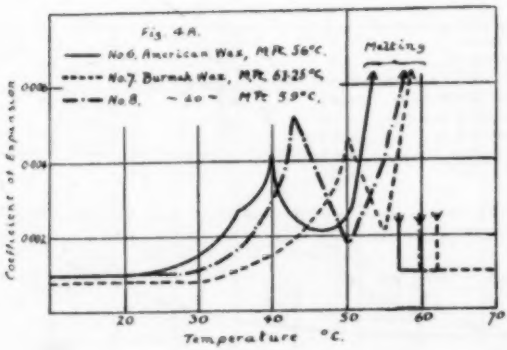
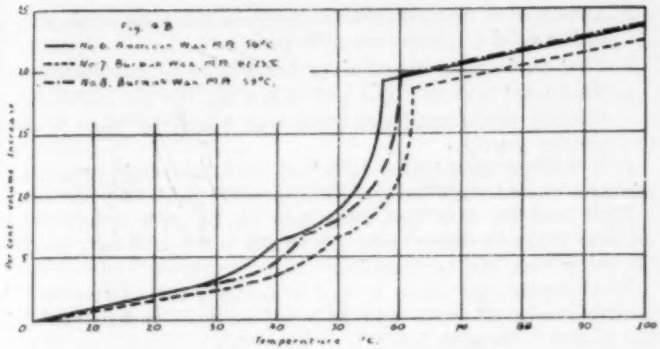
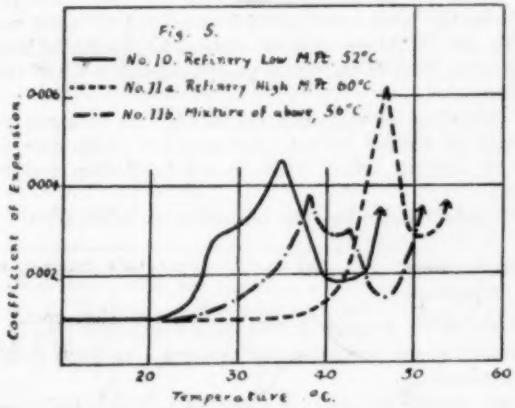


Fig. 4A.
No 6. American Wax, M.Pt. 56°C.
No 7. Burmah Wax, M.Pt. 61·25°C.
No 8, ~ 40 ~ M.Pt. 59°C.
Melting
Coefficient of Expansion
0·006
0·004
0·002
20
30
40
50
60
70
Temperature °C.





A scrutiny of the tables and figures shows that in each case a peak occurs in the curve of co-efficient of expansion with temperature, some degrees below the melting point, this giving a corresponding rise in total expansion with sudden decrease in density. The lower the fraction, the further is this temperature below the melting point.

This phenomenon is capable of more than one explanation, *e.g.* :—

1. That the intermediate peak in the solid phase is due to the presence of a definite constituent melting at the temperature indicated.

2. That one or more transition points between different phases in the solid condition are indicated.
3. That air is being liberated, giving a large volume increase.
4. That cold wax is hard and takes up the expansion with internal strain until this gives way when the mass is sufficiently plastic.

If a definite constituent is mixed with the main wax, then mixtures should show several definite peaks, but they do not.

Figs. 3 and 5 show that when two waxes, with definite intermediate peaks in their curves are mixed, only one peak, between the other two, can be traced.

Furthermore, the more a wax is refined, the sharper is this peak (see Fig. 2A with wax M.P. 65° C.—this wax is probably the purest dealt with here).

It is true that the wax appears greasy and plastic at this point, but it seems to be homogeneous. In all cases, alternative (2) seems to be the most likely as (3) is ruled out by using wax which shows no air liberation, and (4) cannot be operative because the cooling curve follows the same peak backwards when the wax is hardening.

The behaviour of mixtures shows that in intimate molecular aggregates of similar bodies, each molecule influences the other giving an average effect, even in crystallisation and transition changes.

Other data confirming the adoption of alternative (2) above are :—

(*a*) Microscopic observations on crystals formed at definite temperatures.
(*b*) The visible changes in wax masses as they cool.
(*c*) Mottling and air solubility minimum at these definite temperatures.
(*d*) The regular relation between the temperature of maximum expansion when solid and the melting point.
(*e*) Curves showing solubility of waxes in solvents.

Further studies are necessary with highly fractionated waxes, but meanwhile the physical constants given are applicable to problems of storage accommodations and such like.

VI. The Effects of Air and Oil on Wax.

The presence of air in finished wax is intimately bound up with the defect of "mottling" which sometimes appears in candles made from mineral wax and, in order to prevent which, stearins or other substances are sometimes added, producing the masking effect of opacity combined with even separation of air in minute

quantities throughout the mass of the wax instead of in patches. "Mottling" is, as mentioned above, very much increased, together with other defects (see below) by the presence of oil in wax, and is often not so much a matter of increased order of solubility of air in wax as of the manner of internal separation of wax crystals from one another.

When air is shaken with wax, mottling is increased considerably and permeates the wax when the latter is solidified on cooling. When wax is cooled under the protection of air-free water, under pressure, or in vacuo, mottling is eliminated and, if the wax is well refined and free from oil, very little trouble is to be expected in any case.

A few determinations of air solubility in wax were made by allowing a quantity to cool in a small bottle to ordinary temperatures (85° F.), in contact with the atmosphere, and weighed. It was then covered with air-free alcohol or water, and heated to about 160° F. in a water bath, the expelled air being driven over into a measuring apparatus over mercury or alcohol. After correcting for alcohol vapour, etc., the following results, typical of a number of determinations, were obtained :—

Wax.	Volume of air per gram wax. c.c.	Per cent. by volume in wax. %
Burmah low m.pt. wax (m.pt. 52° C.)	0·08 ..	7
Burmah high m.pt. wax (m.pt. 59° C.)	0·12 ..	11
Oily high m.pt. wax	0·145 ..	13
High m.pt. wax + 5% stearin	0·18 ..	16
An American refined wax (m.pt. 56.1° C.) ..	0·13 ..	12
A Borneo wax (m.pt. 57·5° C.)	0·12 ..	11

On shaking the various waxes with air after remelting, the above figures were increased by 2 to 3 per cent. (by volume on wax), depending on the amount of saturation of air in the wax already present.

Air, oxygen, carbon dioxide and nitrogen all give similar effects, though quantitative experiments with these other gases have not been carried out and much more work remains yet to be done.

In this connection the writer begs to acknowledge notes from Messrs. Candles, Ltd. and Messrs. Price's Patent Candle Co., Ltd., from which it appears that their observations on the solubility of air agree with the order of results noted here.

Oil in wax.—The presence of oil in refined waxes brings many defects of a character well known to technologists, and these are not by any means cured by reducing the tint of a wax to dead white by bauxite or Fuller's earth filtration.

The main defects due to the presence of oil, based on observations

obtained with Burmah, Assam, East Indian, American and Persian waxes, are summarised below :—

1. Tendency towards colour reversion (becoming yellow). Wax entirely free from oily and asphaltic material remains perfectly free from colour.

The study of colour reversion in wax and other petroleum products has been carried out in detail, but will not be discussed here.

2. Absence of "snap" and presence of softness, "mealiness" and crumbly nature.
3. A greasy feeling, oiliness and dullness of surface even on rapid cooling.
4. Liability to show excessive mottling.
5. Tendency ultimately to develop excessive translucency on standing or in use. When such a wax cake is broken at this stage, large plate-like laminæ with a "crystallised fruit" or "sugar-candy" effect are noticeable.

This is due to the ability of the wax gradually to separate in large crystals in the presence of oil. Mottling disappears when this condition sets in, but the wax crumbles easily and has very little structural strength.

6. Low breaking strength.

This property has been used here for testing the efficiency of sweating, and the absence of presence of oil in waxes intended for candle making and other purposes.

The following Breaking Strength Test has been applied :—

A cylindrical rod of wax (*e.g.*, a candle of standard size, the test having been evolved chiefly for candles) is supported freely in a horizontal position by resting on two blunt knife-edge fulcra at a standard distance apart, and near the ends of the rod.

A can of known weight is then suspended carefully from the mid point of the rod by means of a wire of standard gauge (*e.g.*, S.W.G. 16).

This can, the weight of which must be well below the expected breaking point, is then loaded gradually by pouring water into it through a fine jet until the rod breaks. The total weight, W, of the can and its contents, is found : the function

$$\frac{Wl}{d^3}$$

then gives a comparative measure in suitable units of the breaking strength of the wax material, where

l = distance between fulcra.
d = diameter of cross section of rod.

The method is only intended for providing comparisons for series of waxes investigated under similar temperature and general conditions, and is not intended to be regarded as standard, though the test, within its limitations, gives reliable and consistent results.

If a candle has been badly moulded, mottled through bad cooling, or imperfectly made in some way, the breaking strength will not give a true measure of the behaviour of the wax, but, this apart, it has been found good for providing orders of magnitude for the determination of good or bad and pure or oily waxes. The addition of hardening materials, such as stearin, is reflected at once, while a series of waxes of successive stages of sweating will show a gradually rising set of values.

The following examples illustrate some results for waxes of approximately the same melting point, resting on fulcra 20 cm. apart, and made into candles of 2 cm. diameter :—

Description of wax.	Nature.	M.pt. ° F.	Tint 18″ cell Lovibond to which filtered.	Tint after 8 hrs. sun exposure.	Breaking weight, grams.
1. An American wax ..	Dull surface, rather crystalline.	133	0·4	5·0	1970
2. Same+3% stearin ..	—	—	—	—	2920
3. A Dutch East Indies wax	Crystalline, somewhat crumbly.	135½	0·7	7·0	1830
4. A well sweated Burmah wax	Tough	138	0·5	5·0	4090
5. No. 4+3% stearin ..	Tough	138	—	—	4550
6. A poorly sweated Burmah wax	Crumbly, mottled.	136	0·6	8·0	1300
7. No. 6+3% stearin ..	Moderately firm.	—	—	—	2000
8. No. 6 resweated ..	Firm	138	0·5	5·5	3000
9. No. 6 further sweated ..	Tough	139½	0·5	4·0	4050
10. No. 4+2% lub. oil base, then filtered to tint	Crumbly, mottled.	136	0·5	15·0	1900
11. No. 4+5% oil ..	Very crumbly, dull mottled.	—	0·5	21·0	1550
12. No. 4+10% oil ..	Very bad	—	0·7	Deep yellow	1400
13. A well sweated Burmah wax	Firm	136	0·5	4·0	3600
14. No. 13+3% stearin ..	Firm	—	—	—	4400
15. Similar to No. 13, but further sweated ..	Firm	141	0·5	1 5	4800

(*Note.*—Nos. 13 to 15 were sweated in "Alanmor" stoves as now installed at the Syriam refinery of the Burmah Oil Co., Ltd.)

Determination of Oil or Wax in Oil-Wax, Wax-Bitumen and Wax-Residue Mixtures.

1. *By acid treatment.*—As an auxiliary rough method of checking in conjunction with the above breaking strength and reversion tests, an indication is given by the depth of colour produced in the acid layer when a known sulphuric acid treatment is given at a definite temperature to a wax filtered to a known tint.

2. *Direct chemical analyses.*—The various methods given in (*a*) Holde and Mueller's "Examination of Hydrocarbon Oils"; (*b*) U.S.A. Bureau of Mines Technical Paper, No. 74, "Physical and Chemical Properties of Petroleum of California"; (*c*) Bureau of Mines Reports of Investigations Serial No. 2655; (*d*) Standard Methods of Testing Petroleum Products, I.P.T. 1924, and other references are all well known and need no comment.

However, the following variation of the method given in Bureau of Mines T.P. 74 was found to be more reliable than others for the determination of wax in dirty or resinous substances such as residues and heavy ends, because it eliminates error due to asphalt:—

About 2 grams of the sample are weighed into a 100 c.c. flask and dissolved in petroleum ether, at least 15 c.c. per gram of sample.

3 c.c. concentrated sulphuric acid are added, and the flask is warmed and shaken at intervals for two hours.

All is allowed to cool and 3 c.c. fuming sulphuric then added. After shaking, the mixture is allowed to stand overnight, shaken again, and tar and acid are separated.

The solution, yellow in colour at this stage, is filtered through ignited bauxite in a glass tube drawn to a point with a narrow opening.

Before the tube is filled with about one ounce of bauxite, a little cotton wool is inserted into the lower end and a layer of bauxite dust, about one inch in depth, is placed on this.

After the solution has been filtered, the bauxite is washed with petroleum ether, adding washings to the filtrate, which should now be colourless. It is evaporated in an air oven and the residue is dissolved by warming with 100 to 200 c.c. ethyl acetate. A volume of 92 per cent. alcohol, equal to half the volume of the ethyl acetate, is added, and the whole is cooled below 0° C. by keeping in ice and salt for 20 minutes. It is then filtered through a filter surrounded with ice; the precipitate is washed with 75 per cent. alcohol and transferred to a small weighed beaker, dried at 90° C. and weighed. A correction of 2·5 mg., per 100 c.c. solvent mixture used, is added to the weight obtained.

3. *Direct mechanical methods.*—Oil-wax mixtures rich in oil, such as paraffin scales and wax distillates, give moderately good results when subjected to a pressure of 2000 lbs. per square inch, though refined waxes containing small quantities of oil are not easily determined by this method.

An ordinary hydraulic crushing machine, used for the determination of compressive strengths of cements, was fitted with a special fitment consisting of a heavy steel cylindrical plate, 5 in. diameter and $\frac{3}{4}$ in. thickness. The face of this was hollowed out, so that a heavy ring, of $4\frac{1}{2}$ in. external diameter, $3\frac{1}{2}$ in. internal diameter, and 1·1 in. height would fit snugly into it forming a cup. A plunger, fitting this exactly, was pressed down with the registered force of the press on to a known quantity of scale resting on a sufficient pad of filter paper or other absorbent material placed in the bottom of the hollow. Both the expressed oil and the wax could be weighed directly. The results obtained by this means checked up well against the longer chemical determinations, but naturally depended on the temperature of operation; knowing the proportion of low melting wax required to give the expressed oil a given set point, this could be allowed for.

VII. Amorphous and Crystalline Wax.

Several attempts have been made to transform amorphous wax or mineral jelly into crystalline varieties, but unless definite chemical changes of a drastic nature (*e.g.*, cracking), coupled with the production of gas, coke or other products, have taken place, no definite transition of amorphous into crystalline substance has been obtained—*i.e.*, the *same* compounds do not exist in the two forms.

Mineral jelly and crystalline wax appear to belong to two different classes of organic compounds; the former is of an unsaturated nature and resembles a lubricating oil of high flow point, while the latter is a saturated body and does not possess the same lubricating properties.

Amorphous jellies are less volatile and more soluble in liquid mineral oil fractions than crystalline waxes; they possess appreciable iodine values against nil values of the latter substances.

It was found that an amorphous jelly-like filtered residue, obtained from the distillation of a Burmah (Yethaya) crude, contained some 25 per cent. of true crystalline paraffin in solution, as determined by the method outlined in the last section.

This residue was distilled in steam under conditions of minimum cracking. The individual fractions of distillate at first showed the visible presence of crystalline paraffin, but analysis o the whole, distillate showed a total content of 22 to 23 per cent. crystalline paraffin only, the difference being accounted for by decomposition.

From this and many other observations, it is considered that, though actual cracking has produced the apparent transition as reported in several published papers, many of the so-called changes have simply been fractionations of solutions by distillation, furthermore, it is a delicate matter, if cracking a heavy end not to destroy crystalline paraffins also.

Summary.

I. Results obtained from the fractionation of wax from Burmah crude point to the presence of the complete range from $C_{21}H_{44}$ up to $C_{34}H_{70}$. In some cases isomers of these with different melting points for a given molecular weight are indicated.

II. A pure hydrocarbon of melting point 96·5° C. has been obtained from mineral wax occurring in the Singu Field of Burma.

The formula is probably $C_{57}H_{116}$, and this is believed to be the highest member of the paraffin series yet isolated from a purely mineral wax.

III. Observations on the cooling of wax in mass and its crystallisation from organic solvents, including mineral oil fractions, point to the existence of a transition point between two crystalline forms, some 10° to 15° C. below the melting point, and possibly another point at a lower temperature.

IV. Above this transition point needle shaped prisms are stable, while below the transition point rhomboid plates or leafy masses are obtained.

Slow cooling favours the former, and their initial presence is favourable to the refining of wax from oil-wax mixtures, even if more rapid cooling is carried out in a subsequent stage after the mass has been seeded out with these crystals.

V. Determinations of solubility in solvents and of expansion curves, together with observations on air solubility at different temperatures, give data for fixing these transition points which ascend with the successive members of the of the homologous series, and are related to the melting points. The expansion curves give discontinuities near these points, showing that the needle-shaped crystalline varieties have a much lower density than would be expected from those of the foliaceous forms.

The total expansion of a wax from the state of solid at ordinary temperatures to that of liquid just above the melting point is from 15 to 17 per cent.

VI. Wax dissolves easily from 7 to 15 per cent. of its own volume of air at ordinary temperatures, and when saturated, particularly if the wax is oily, may show the phenomenon of "mottling."

The presence of oil in wax also produces several other well-known defects in the form of crumbliness, mealiness, colour reversion and low breaking strengths. A comparative test for determining the breaking strengths of waxy materials is described, and has been used as an aid to the determination of refining efficiency.

VII. Amorphous mineral jellies and crystalline waxes belong to totally different chemical classes of compounds and are not isomeric.

Separation of one from the other has sometimes been mistaken for transformation, but, short of bringing about drastic decomposition of jelly into more than one class of body by cracking, it does not appear possible to obtain crystalline paraffins from amorphous jellies by a simple transformation.

In conclusion, the writer, in addition to acknowledgments given in the text, wishes to express his thanks to Mr. H. L. Allan, Refinery Manager of the Burmah Oil Co., Ltd., Syriam, for helpful facilities and suggestions, to Messrs. J. Henry, B.Sc., S. J. Mallinson, B.Sc., A. Sirker, M.Sc., and Lim Loke, of the Burmah Oil Co., Ltd., Syriam, for part assistance in the experimental work, and to the Directors of the Burmah Oil Co., Ltd., for permission to publish this paper.

Working Hypotheses in the Geological Search for Oil.

By Murray Stuart, D.Sc., Ph.D., F.G.S., F.C.S.

The geologist, or prospector, searching for oil deposits has always been handicapped by the fact that very little, if anything, is known concerning the origin, or origins, of the oils occurring in the various oil deposits of the world. The laws governing the migration and accumulation of oil into pools of commercial value have been fairly thoroughly worked out, but the question of how the oil itself originated remains unsolved. Consequently, although the geologist knows what structure to look for when it is known that the strata are oil-bearing, he has very little to guide him to the oil-bearing strata, unless the oil discloses its presence by seepages or already has been proved to exist at known geological horizons in territory adjacent to that being investigated.

The object of the present paper is to consider some of the research work that has been done, and the theories that have been put forward, concerning the origin, or origins, of known oil deposits, and to see whether it is possible to build up certain working hypotheses which will be a help and a guidance to the geologist in search of oil. It is not suggested that such working hypotheses will be anything more than a beginning of the attempt to explain the conditions governing the various origins of oil, but from the wealth of evidence available it seems possible to propound hypotheses which further discoveries may only modify in details and not in main principles, and which consequently will not be seriously affected as regards their practical application to oil geology, and it is as working hypotheses for the field geologist, rather than as attempts to solve a scientific problem, that they are put forward.

Several years ago the carbon-ration hypothesis was propounded by David White as a working hypothesis applicable to oil geology. Summed up briefly by Dr. Arthur Wade in his paper recently read before this Institution on "The Search for Oil in Australia," the hypothesis at the present day is as follows:[1]

"Numerous investigations in American oilfields have established the fact that the degree of metamorphism undergone by coal seams gives some measure of the chances of obtaining oil and natural gas in the associated strata. That is to say, there is a stage in the changes undergone by coal seams which corresponds with the natural conditions under which carbonaceous matter becomes petroleum. The percentage of fixed carbon in a pure coal is taken as the measure of metamorphism. The analysis of an

[1] *Journ. Inst. Petr. Techn.*, Vol. XII., No. 55, pp. 158, 159.

ordinary coal is usually given under the headings of moisture, volatile matter, fixed carbon, and ash. From these we eliminate ash and moisture and the percentage ratio of fixed carbon to the volatile matter is the basis of our hypothesis. Fuller gives the relative chances of finding oil corresponding to the ratios obtained by this method as follows:—

Zone of 50 to 55 carbon ratios	..	..	..	100
,, 55 to 60 ,,	,,	..	..	..	10
,, 60 to 65 ,,	,,	..	..	..	probably less than 1."

In connection with the American oilfields remarkably accurate results have been obtained from the application of this hypothesis, but Dr. Wade goes on to point out that the hypothesis must be applied with caution, and he quotes the instance of carbon-ratios worked out from analyses of coals in the Sydney-Newcastle-Maitland coalfield of Australia, where carbon-ratios exceeding 60 are obtained from the coals of the middle and upper coal measures, while from the Greta coals, which lie at a depth of over 7000 ft. below the base of the middle coal measures, carbon-ratios of 50 and 55 are obtained. He points out this is a difficulty, "for if the carbon-ratio represents the degree of metamorphism which has taken place in the strata, we should expect to find higher ratios in these lower coal measures than in the upper ones."

In other words, although in many instances remarkably accurate results have been obtained from the application of the carbon-ratio hypothesis, it is not, in its present form, suitable for universal application.

The part of the hypothesis that seems open to amendment is the suggestion that the carbon-ratio of a coal is anything to do with metamorphism undergone by the coal seam subsequent to its becoming a member of a series of geological strata. The careful investigations of L. Lemière indicate that differences in composition in coal seems, not only between adjacent seams but also between the various bands in the coal seam itself, are mainly original, the denser and more anthracitic varieties representing plant substance which has been more completely macerated and deprived of its putrescible constituents before being laid down.[2] This is in direct opposition to the idea that the carbon-ratio of a coal is a measure of the metamorphism it has undergone subsequent to its formation, and it seems desirable to see whether the hypothesis can be revised so as to eliminate the question of metamorphism.

As is the case with oil, so with coal, no one explanation can be given which will explain the mode of formation of all coal deposits, but it is generally accepted now that ordinary coal was formed from the decomposition of plant substances in fresh water

[2] *Bull. Société de l'Industrie Minerale*, 4 Ser. Vol. IV., pp. 851, 1299; Vol. V., p. 273.

swamps or lagoons under bacterial action, and that on such swamps or lagoons being broached the material derived from the decomposition of the plant substances was deposited in estuaries or the open sea as a black carbonaceous mud which on consolidation became coal. The bacteria responsible for this change have been detected by B. Renault in the woody parts preserved in coal, and also in fragments of wood fossilised by silica or carbonate of lime which are sometimes met with in coal seams. One of these bacteria, *Micrococcus carbo*, bears a strong resemblance to the living *Cladothrix* which is found in trees buried in peat bogs.[3] These bacteria thrive in fresh water but are killed by brackish or salt water. Consequently it would appear that when a fresh water swamp or lagoon, in which plant substances had been undergoing decomposition under the action of carbonizing bacteria, was broached, and the products of such decomposition were carried by rivers and laid down in estuaries or in the open sea, further action of the carbonizing bacteria naturally ceased, owing to the salt or brackish water in which the black carbonaceous mud was laid down as a sediment. This obviously explains why ordinary coal is laminated, and is found to consist of thin layers each differing from its neighbour in brightness and in the degree of dissociation of its carbon content. Each thin layer is a geological stratum, a fact that has been established by careful mapping of individual layers extending over long distances, and the degree of dissociation of its carbon content depends upon how far such dissociation had proceeded under bacterial action in fresh water swamps or lagoons before the material was carried into brackish or salt water and there laid down as a sediment.[4] In other words, the carbon-ratio of any coal seam as a whole, or of any particular band in that coal seam, would appear to depend upon how far decomposition of the material composing that seam or band had proceeded as a result of bacterial action before it was first laid down as a sedimentary deposit. It follows from the above that the amount of volatile matter in any particular coal is original, and has not altered much in amount since the coal was first laid down as a seam. It is proposed therefore to review the carbon-ratio hypothesis, as applicable to oil geology, from the above standpoint, and to see whether it is possible to make it of more general application than it is at present.

It is not denied that occasional instances must occur where oil is the direct result of the metamorphism of coal seams. In

[3] *Bull. Société de l'Industrie Minerale*, 3 Ser., Vol. XIII., p. 865.

[4] The above is taken from a series of advanced lectures on "Coal," delivered by the late Prof. Charles Lapworth at Birmingham University in 1906.

fact the author has described one such case where commercial oil deposits in Burmah would appear to have been derived from lignites as a direct result of their having been involved in overthrust faulting. Such cases, however, must be the exception rather than the rule, and it is proposed to ignore them in the following discussion and to deal with the case of coal seams which it is assumed have not undergone any appreciable metamorphism. In doing so the geological aspect will be considered first to the exclusion of the chemical aspect of the case, which will be discussed at a later stage in the paper.

If ordinary coal was formed in the way outlined above, it follows of necessity that its accumulation must have been governed by the ordinary laws governing the accumulation of ordinary geological sedimentary strata. If we consider the concrete case of the Eocene lignites of Burmah, which are jet black, well laminated, coals accumulated under marine conditions,[5] it is obvious that the material which now forms the coal seams does not represent the whole of the material that was carried by rivers into the sea. The carbonaceous material as it was carried into the sea by rivers must almost certainly have been associated with mud, sand, and possibly pebbles, in fact, all the ordinary sedimentary material usually transported by rivers. This mixture when carried into the sea would become sorted out as it settled through the still waters of the sea, the coarser material would settle first and be deposited close to the land; this would be followed by sand, which would be carried further out from the land; still further out the ordinary mud would settle; and finally, furthest out of all the carbonaceous mud would settle. A sheet of sediment would be obtained therefore which would consist of conglomerate at one end, passing through sand, and then shale or clay, to more or less pure carbonaceous material at the other end. If the plant substances which gave rise to the carbonaceous material did not contain any appreciable quantity of resinous or oily material, the lateral variation of the sheet of sediment would be roughly that postulated above, but if the plant material did contain an appreciable quantity of resinous or oily matter, the case would be slightly different. Again, to take a concrete example, if the plant substances which underwent fresh water carbonisation contained a large proportion of material derived from the genus *Dipterocarpus*, then there would be a large quantity of resinous substances and wood-oil present in the material. *Dipterocarpus* forms wood-oil and resin in large quantities in its leaves and wood,

[5] *Journ. Inst. Petr. Techn.*, Vol. XI., No. 52, pp. 475–486 (1925).

particularly in the leaves, and it is conceivable that quite large quantities of oil and resin would be liberated during the decomposition of such vegetation by fresh water bacteria. Some of this oily and resinous material would almost certainly remain intimately associated with the solid products of the carbonisation of the plant substances, but it seems reasonable to assume that a large proportion of it would be set free. When the swamp or lagoon in which such carbonisation had been taking place became broached, and the material from it was drained off and carried out to sea by rivers, the free oily material present would be deposited with the clay, either as free oil in the manner demonstrated by the author in his paper on the "Sedimentary Deposition of Oil,"[6] or possibly by first combining with colloidal inorganic matter to form "gels" which would then be deposited with the clays. The same reasoning would apply to the resinous spores of plants which would be deposited by clay in exactly the same way as the author has demonstrated that globules of oil are deposited. The sheet of sediment obtained under these conditions would consist of conglomerate at one end, passing through sand and shale to oil-bearing shale, which would pass through something equivalent to Torbanite into more or less pure carbonaceous material at the other end. In other words, the sheet of sediment when consolidated would exhibit coal passing gradually into oil-shale, or liquid oil deposits, and this in turn into ordinary shale, sandstone, and finally conglomerate. Now there are so many examples known in the world of coal seams and lignite seams passing laterally into either oil-shales or oil deposits that it seems possible that the carbon-ratio hypothesis as at present propounded should be amended so as to exclude the idea of metamorphism, and to substitute in its place the ordinary laws governing sedimentary deposition. In other words, that if the carbon-ratios indicate that the coal contains a sufficiently high percentage of volatile matter, and the author sees no reason at present why the present hypothecated values of the ratios should be altered, there seems to be a possibility that the seam will pass laterally into either oil-shale or oil deposits when traced towards the direction from which the material was originally transported. The above working hypothesis applies to an individual coal seam. If the seams are numerous in a coal measure series it can be applied in a modified form to the coal measure series as a whole. If the geology of the country is not sufficiently known to indicate the direction from which the material forming the coal measures was transported, curves drawn

[6] *Rec. Geol. Surv. Ind.*, Vol. XL., Part 4, p. 321–333 (1910).

through places where similar carbon-ratios are obtained from analyses of the coals—known as "isovolves" or "isocarbs"—may indicate this, but care must be taken to see that analyses from the same seam, or group of seams, are used in the construction of such isovolves. It is obviously useless to map an isovolve in, say, upper or middle coal measures and another in lower coal measures, and attempt to draw any conclusion from a comparison of the two.

Now, series of strata known as coal measures usually consist of alternations of shale, coal, and sandstone, alternating with one another. There is no hard and fast rule as to the order in which they are arranged, or as to their relative thicknesses, the succession being determined by local changes in the conditions of deposition during the period they were accumulating. If the carbon-ratio hypothesis as amended by the author holds good, then it is only to be expected that sometimes Torbanites and oil-shales, or liquid oil deposits, should be found interbedded in a coal measure series just as it is equally possible for coal seams to be present at intervals in an oil-bearing series. For example, the bands of Torbanite in the upper coal measures of North Staffordshire, and the seepages of oil that occur low down in the coal measures in the same area, are explained by the hypothesis as amended, as is also the fact described by Dr. Bosworth in his "Geology of the Mid-Continent Fields," that "Coal seams are present at intervals throughout a great part of the oil-bearing formations." The case of the Greta coals in the Sydney-Newcastle-Maitland coalfield of New South Wales also becomes highly significant. Dr. Wade quotes Prof. Sir Edgeworth David as stating that "the Greta coals all carry *Reinschia australis*, the body which when concentrated forms kerosene shale." It would appear therefore that the lateral variation of the sheet of sediment of which the Greta coals constitute one portion would include the passage of coal into oil-shale. In other words, that if the geological horizon of the Greta coals could be followed in the direction from which the detrital material forming the strata was originally derived, the coals would be found to pass gradually into oil-shale.

To leave for the moment further consideration of the geological relationship of coals with oil shales and oil deposits, and to turn to another form of oil deposits, oil is frequently found to occur in dolomitised limestones of lagoon formation. Such oil deposits frequently do not appear to be related in any way to coal or lignite. This would be quite in accordance with the working hypothesis suggested above, since the oil deposits and oil shales accumulated in accordance with that hypothesis must all come under the heading of Mechanically-formed or Detrital deposits,

whereas limestone deposits come under the heading of Organically-formed deposits, and are generally accumulated beyond the zones where detrital material is being deposited. In all previous discussions on the sedimentary deposition of oil, and the relationship of fossil-wood to oil, the author has always carefully excluded the case of the limestone oils as not coming into that particular question since it seemed obvious that they must owe their accumulation, and therefore probably origin, to some different causes.[7] Now dolomitic limestones containing oil deposits are frequently highly organic and often contain abundant fossil foraminifera. For example R. K. Richardson writing of the Asmari limestone of South West Persia states :—"The rock is highly organic, being a richly foraminiferal limestone in which the bulk of the remains are only revealed on microscopic examination."[8] Such dolomitic limestones would appear to have accumulated in salt lagoons or some part of the sea that had ceased to be in open circulation with the ocean and had become stagnant. It is known that such stagnant places become characterized by accumulations of organic matter, by the development of sulphuretted hydrogen in the water, and by *the disappearance of bottom living animal organisms* owing presumably to the fact that they speedily consume all the available free oxygen from solution in the bottom layers of the water which cannot then support their life. Although under such conditions the bottom living animal organisms are unable to continue existence, certain forms of bacteria continue to exist and apparently to thrive. Pirsson and Schuchert state that "such bottom waters are said to be stale, and they are taken possession of by sulphur-making bacteria which feed upon the micro-organisms and other life that falls from the sunlit, oxygen absorbing surface zone."[9] The method of "sulphur-making" appears to be that, either directly or indirectly, oxygen is removed from soluble sulphates, reducing them to sulphides ; these sulphides then reach with water with the resulting liberation of sulphuretted hydrogen. Now just as to explain an electric current and to describe the various laws which govern its phenomena the assumption is made of an actual flow of something analogous to a flow of water along a pipe, so in this case for the sake of convenience it is proposed to assume for the moment that the particular bacteria under discussion that inhabit the stale bottom waters of stagnant salt water, need oxygen, but whereas mammals and land animals obtain it from the air direct, and fish and aqueous animal organisms obtain it from

[7] *Rec. Geol. Surv. Ind.*, Vol. XL., Part 4, p. 330 (1910). *Economic Geology*, Vol. IX., No. 6, p. 597 (1914).
[8] *Journ. Inst. Petr. Techn.*, Vol. X., Part 43, p. 263.
[9] *Vide* Dewhurst, *Journ. Inst. Petr. Techn.*, Vol. IX., Part 39, p. 357.

solution in water, that these bacteria obtain it by breaking down chemical compounds, as for instance by taking the oxygen out of the SO_4 radical. Whether the action is as direct and simple as postulated in the above assumption or whether it is more involved, one result of the action is known to be the reduction of soluble sulphates to sulphides, and as the method by which the result is produced will not have much effect on the discussion below, it is proposed to make the assumption for the sake of convenience in discussing the results of the action of such bacteria. One result of their action will be the reduction of magnesium sulphate present in solution in the water to magnesium sulphide which will reach with water to produce sulphuretted hydrogen and magnesium hydroxide, which would appear take part in the formation of dolomite. Now if the bacteria, to obtain oxygen, can break down the SO_4 radical and take the oxygen out of it, there seems to be no reason why they should not be able under certain circumstances to split up the H_2O molecule and take the oxygen out of it. It also seems reasonable to expect that they would take the oxygen out of the protoplasm of the dead foraminifera and micro-organisms on which they feed. The reduction of these chemical compounds might not be accomplished with equal ease; for instance, it is conceivable that it would be less difficult to take the oxygen out of the SO_4 radical than to split up the H_2O molecule and extract the oxygen from it, and it is possible that when free swimming, and not attached to any dead organic matter, the bacteria may limit their oxygen acquiring activities to taking the oxygen out of the SO_4 radical of soluble sulphates. When, however, a dead micro-organism settled from the sunlit, oxygen absorbing surface zone, through the stagnant and stale bottom water, to rest finally on the bottom, its protoplasm would be seized upon by the bacteria which would then become more or less fixed, and under these conditions when they had exhausted all the soluble sulphate within reach they would have to turn to some other liquid containing combined oxygen for their oxygen supply. The obvious liquid that would be available is water. In splitting up the H_2O molecule it seems not unlikely that the bacteria would fix the hydrogen and take the oxygen. The taking of the oxygen out of the dead protoplasm and out of the water molecule may have been simultaneous in some cases, but it would seem that the fixing of the hydrogen atoms from the water molecule on to the protoplasm material must have synchronised with the liberation of the oxygen of the water molecule. With oxygen being removed from the dead protoplasm and hydrogen being added to it, the resulting formation of saturated hydrocarbons begins to appear as a vague

chemical possibility. The presence of nitrogen in protoplasm is a distinct difficulty, but if by any chance it was linked, either wholly or in part, with oxygen atoms in original chemical structure of protoplasm, it is quite conceivable that on oxygen being taken out of the complex the nitrogen might be freed, either as free nitrogen, or more probably as NH_3 which would then be available as it diffused towards the surface to provide the nitrogen necessary for the growth of future foraminifera and marine organisms, establishing in fact one of the cycles nature is so fond of employing. With the nitrogen and oxygen removed all that would be left of the original protoplasm would be carbon and hydrogen in chemical combination and the hydrogenation of such into saturated hydrocarbons advances from a vague chemical possibility into almost a probability. It also seems not impossible that the particular members of the saturated hydrocarbon series to be produced might be a function of the relative speeds at which hydrogenation and deoxidisation of the dead protoplasm were taking place. If the change into saturated hydrocarbons as the result of bacterial action on dead protoplasm took place after the dead organism had settled to the bottom, as there is every reason to assume that it did, then by the time that globules of oil had formed it is quite conceivable that they would be covered by sufficient shells of dead foraminifera to prevent the oil floating to the surface, in other words, to keep the oil in the calcareous sediment. Also since the dead organism in sinking to the bottom passed through water in which sulphuretted hydrogen was being generated, it is only to be expected that the protoplasm, which is a semi liquid permeable to water, should acquire a certain amount of sulphuretted hydrogen and that the oil, which is the ultimate product of the decomposition of the protoplasm with which this paper is concerned, should in consequence contain sulphur.

If the above is an approximate description of what might be expected to happen, the question naturally arises as to what, under such circumstances, would become of the oxygen which the bacteria acquired by the decomposition of chemical compounds containing combined oxygen? It would seem a strange reversal of the action of the bacteria if, after extracting the oxygen from chemical compounds containing combined oxygen, they then combined it with either carbon or any other element or compound. In other words, it would appear unreasonable to suppose that the oxygen would be given off in chemical combination as CO_2, or that it would be combined by the bacteria with hydrogen derived from the dead protoplasm to form H_2O. The most reasonable supposition to make is that these bacteria liberate the oxygen into

the water as free oxygen; that they represent, in fact, an effort of Nature to resist change, and that as the oxygen ordinarily present in solution in salt water becomes exhausted when the water becomes stagnant through being used up by the animal life in the water, these bacteria which feed on the dead bodies of marine organisms begin to thrive and to furnish oxygen to the water.

In acting in this way the presumed action of the bacteria is not unsimilar to certain actions that take place in the vegetable kingdom. For instance, land plants break up the CO_2 molecule which they obtain from the atmosphere and return the oxygen from it to the atmosphere as free oxygen. The breaking up of the H_2O molecule is also not unknown. A young teak tree can be grown in pure silica sand free from all soil or humus. Its carbon is naturally derived from the CO_2 of the atmosphere, but the combined hydrogen of its tissues can only have been derived from the breaking up of the H_2O molecule and the fixing of the hydrogen atoms on to the plant tissues.

The assumption that these bacteria would liberate free oxygen into the water raises the question as to why the bottom living animal organisms disappear. The answer seems to be that these bacteria do not begin to thrive until the water has become stagnant and most of its dissolved oxygen has been exhausted, and that after they begin to thrive the lower layers of the water become contaminated by sulphuretted hydrogen, which is an animal poison. It would appear that only substances in solution in the water, or semi-fluid substances like protoplasm, or possibly more highly organised organic tissues if permeable by water, can be attacked by these bacteria, and that solids such as calcium carbonate and dolomite are not affected by their action.

It would follow therefore that oil may be expected in a dolomitised limestone of lagoon formation provided that the conditions under which it accumulated were such that the lower layers of the water in which it accumulated were stale and exhausted of most of the dissolved oxygen, while the sunlit, oxygen-absorbing zone was inhabited by foraminifera and other protozoa. Since it has been assumed that the bacteria responsible for the formation of saturated hydrocarbons from the decomposition of protoplasm decompose chemical compounds containing combined oxygen and liberate free oxygen into the stale water in which they thrive, it follows that as the amount of free oxygen dissolved in the water increases so their activity would decrease and that their action would more or less cease when the amount of dissolved oxygen approached the amount usually present in

circulation in ordinary sea water, and this would explain why all limestones are not oil-bearing. Nummulitic limestones, for instance, are foraminiferal limestones, but it is difficult to imagine nummulites being anything but bottom living organisms, and it would appear, in consequence, that the bottom layers of the waters in which they thrived must have contained the ordinary amount of dissolved oxygen usually present in sea water, and so not have been suitable for what may be termed the oil-producing bacteria to thrive in. Under these conditions the protoplasm and dead organic organisms which were not eaten by other organisms would probably undergo totally different decomposition under the action of totally different bacteria which thrive in ordinary oxygen-containing water.

In view of the above hypothesis, the case of ordinary marine sediments becomes interesting. Speaking generally, clays and shales and sandstones of marine origin are of a bluish colour. This bluish colour is found to be characteristic of rocks through which iron disulphide is distributed in extremely minute subdivision.[10] In seeking for the explanation of the presence of the iron disulphide one's mind goes irresistibly to the sulphuretted hydrogen generated as a result of the action of the bacteria that have been under consideration, since in the ordinary course of events the change from ordinary ferruginous material into sulphide of iron must have taken place after the detrital material had been carried into the sea. Now, although more or less inactive under ordinary conditions in the sea, these bacteria are presumably present and only waiting for a portion of the sea to become stagnant and the dissolved oxygen in it to become exhausted for them to become active. Although sea water in which detrital material is being laid down in the form of sediments is to a certain extent in circulation, and can be supposed normally to contain the ordinary amount of dissolved oxygen, the interstitial water which occupies the spaces between the particles composing the upper layers of the accumulated sediment must speedily become stagnant and its dissolved oxygen exhausted, either through being used up by microscopic animal life living in the water or by the bacteria that thrive in oxygen-containing water and feed on dead organic matter. As soon as that happens the sulphur-making bacteria can become active with the liberation of sulphuretted hydrogen; and the consequent transformation of any ferruginous matter in the sediment into sulphide of iron would follow as a natural result. Since the sulphur-making bacteria seem to be essentially salt-water bacteria, this would account for the general

[10] Sir A. Geikie, "Text-book of Geology," p. 139 (1903).

bluish colour of marine detrital deposits as against the yellow, brown, or reddish colour of detrital sediments accumulated under fresh water conditions.

If therefore the conditions under which marine clays and shales accumulated were such that foraminifera, or radiolaria, or any protozoa, or diatoms, were included in them in appreciable quantity, one would expect the protoplasm of the organism to be converted into petroleum in exactly the same way as has been described above in the case of a foraminiferal dolomitised limestone. In the case of the dolomitised limestone foraminifera were specifically considered since the accumulation of the limestone is dependent on the supply of the calcareous shells and tests of marine organisms. Radiolaria would not fulfil that necessary condition and therefore they were not introduced into the question of the formation of a limestone. Since, however, it is the protoplasm that undergoes change into petroleum, and not the shell or test of the organism, any protoplasm entombed in shale would undergo that change. The shale itself would constitute the sediment that held and retained the oil after it was formed, and therefore it would not matter whether the organism furnishing the protoplasm had a calcareous shell, or a siliceous skeleton, or had no shell or frame work at all. Furthermore the oil that was formed in such shales would not necessarily be squeezed out of the shales into adjacent sand beds under the pressure caused by the weight of accumulating superimposed strata to the extent that globules of oil deposited with mud as a sediment are. The latter case is discussed fully in the author's paper on the "Sedimentary Deposition of Oil" already referred to. The case of oil formed in a foraminiferal shale would be slightly different, however, in that the shells and tests of the organisms would very largely resist compression due to the weight of accumulating superimposed strata, and in their hollow interiors provide spaces in which the oil could remain, and so a foraminiferal shale might remain the home of the oil. In Nature it is probable that both things take place; a certain amount of the oil is squeezed out of the shale into an adjoining sand and a certain amount remains in the foraminiferal shale. As evidence that such has occasionally happened the case of the Californian oilfields may be referred to, where Arnold and Anderson have found conclusive evidence that the oil originated within diatomaceous Miocene shales. Not only are these diatomaceous shales (Monterey shale) the source of the oil, but it has been shown that the oil can be traced to those parts of the shales that are characterized by the presence of an abundance of the remains of diatoms and foraminifera. Elsewhere, where the shales do not contain the remains of diatoms and foraminifera they, and the sandstones in contact with them, are barren of oil. In the Coalinga

oilfield the Monterey shale is absent but its place is filled by the Tejon shales, which show the same phenomenon. Where they are characterized by the presence of abundant diatomaceous and foraminiferal remains they are associated with oil, and conversely where they do not contain diatomaceous and foraminiferal remains they are not associated with oil. In Trinidad also the same thing has been noticed. Dr. Illing in his discussion of Mr. Ernest Clark's paper on the "Organic Theories of Oil Origin," published in this number of the Journal, quoted instances of oil occurring in foraminiferal clays in Trinidad, and mentions one instance where the conditions were essentially marine. There was no chance of migration from that deposit, and the oil came from something that was in the particular clays and the only organic deposit in those clays was foraminifera.

Although such instances are known, it would seem that they are distinctly the exception and the result of some special combination of conditions, and that in most cases sea water in which clays and shales are accumulating is not suitable for a profusion of foraminiferal or radiolarian or diatomaceous life; and for the most part the clays and shales that occur in the Geological Record are not characterized by the presence in them of an abundance of foraminiferal or diatomaceous remains. Moreover, under normal conditions the struggle for existence on the sea floor is just as intense as it is on land. The supply of predatory forms is quite equal to the supply of food, and the amount of protoplasm and animal tissue that escapes being eaten and becomes buried up in the accumulating sediment is so small as to be negligible. If, under normal circumstances, any protoplasm or micro-organism did escape being eaten after death it would be decomposed as it lay on the sea floor by the bacteria that inhabit and thrive in normal aerated sea water into CO_2, H_2O, and NH_3, before it had time to be entombed in sediment.

The accumulation of abundant foraminiferal or diatomaceous remains *with their protoplasm* in shale would appear to necessitate some such stagnant condition as has been postulated for the accumulation of the dolomitized foraminiferal limestones in order to eliminate the bottom living predatory forms and the bacteria that thrive in normal aerated sea water. If one thinks of such accumulations as argillaceous foraminiferal limestones rather than as foraminiferal shales, even though they do not exhibit the degree of consolidation one usually associates with the word limestone, it helps to correlate the oil found in them with the limestone oils. If, however, certain mud was deposited containing globules of oil derived from the oil of land vegetation, such as has been described in the first part of this paper, the oil globules imbedded in the top

layers of the accumulating mud might quite easily be attacked by the sulphur-making bacteria, with the result that the combined oxygen of the oil would be taken out of the oil molecules and at the same time hydrogenation take place. The same thing might also occur in the case of mud containing certain resinous spores of plants. In fact, the conversion of the vegetable oil into saturated hydrocarbons might be almost exactly similar to the conversion of dead protoplasm into saturated hydrocarbons, which has been discussed above. The bacteria, since they are apparently responsible for the conversion of dead protoplasm into oil, must be able to work in an oil medium, otherwise the complete conversion of protoplasm into oil would not appear to be possible. Also, in the case of oil globules deposited with mud, the difficulty of bottom living predatory forms does not arise. Globules of vegetable oil are not the natural food of bottom living predatory forms, and it is unlikely that such forms would take any interest in them. Therefore no special conditions, such as stale stagnant bottom waters, or the absence for any reason of bottom living predatory forms, are necessary for the accumulation of globules of oil in mud as a sediment, and there seems no reason to suppose that they could not be deposited and accumulate with mud under ordinary marine conditions. Consequently it would appear that the same bacteria may have been responsible for both the formation of the oil now occurring in dolomitised limestones of lagoon formation and for the conversion into saturated hydrocarbons of vegetable oil which was deposited with mud as a sediment. The similarity between the two differently formed oils would be explained in this way, as would their similar optical activity, since both would owe their existence to the action of the same bacteria. Also the chemical differences between the different naturally occurring liquid petroleums of the world would be explicable since, although the theoretical ultimate result of the bacterial action would be saturated hydrocarbons, it is only to be expected that the action would practically never proceed to absolute finality, and therefore traces of incomplete conversion would remain and these would naturally differ in each case with the different substance, protoplasm or a particular vegetable oil or association of particular vegetable oils, that was acted on by the bacteria.

The question would then arise why, if most liquid petroleums have been produced by the action of the same bacteria, should limestone oils generally contain sulphur and the petroleum found in a shale and sandstone series generally be comparatively free from sulphur? The explanation seems to be that the dead protoplasm that gave rise to the oil occurring in dolomitised

limestones of lagoon formation must have been sodden with water containing sulphuretted hydrogen in solution before the bacterial action on it commenced, and so the oil produced from the dead protoplasm might be expected to contain a certain amount of sulphur, whereas in the case of vegetable oils deposited as marine sediments with mud, the oil would not come into contact with sulphuretted hydrogen under normal circumstances until the sulphur-making bacteria became active in the sediments themselves, and under such circumstances the sulphuretted hydrogen produced would not only be small in quantity but such as was liberated would immediately combine with the ferruginous material present in the sediment to form sulphide of iron.

Since it would appear that the sulphur-making bacteria are essentially salt water bacteria, it would follow that when mud containing oily matter was laid down in the sea the oily matter would under ordinary circumstances be converted into liquid petroleum, but that when such mud containing oily material was laid down in brackish or fresh water the transformation into liquid petroleum would not take place. At this stage it might not be inappropriate to refer to Mr. Cunningham Craig's suggestion in his paper on "Recent Researches bearing on the Origin of Petroleum" that a torbanite would probably be entirely liquefied if subjected to Dr. Bergius' hydrogenation process.[11] If in the above suggestion the natural processes of the sulphur-making oil-producing bacteria are substituted for Dr. Bergius' hydrogenation process, then the author is inclined to agree with part of it. In other words, in some cases a torbanite would appear to be a torbanite because it was deposited in brackish or fresh water. Had it been deposited as a marine deposit, liquid petroleum would probably have been produced as a result of the action of the sulphur-making oil-producing bacteria on any vegetable oily matter contained in the torbanite. Whether the liquid petroleum produced would then have become contained in a sand or whether it would have remained as a kerosene shale would appear to depend on whether a sand was available for the oil to be squeezed into,[12] but it seems probable that in most cases it would have been able to migrate into a sand.

In view of the above reasoning the case of the coal measures of North Staffordshire becomes significant. These have already been referred to in the earlier part of the paper. Now the conditions under which the British coal measures accumulated are admirably summed up by the late Prof. Lapworth in his Text-

[11] *Journ. Inst. Petr. Tech.*, Vol. IX., No. 39, pp. 346, 350.
[12] *Vide Rec. Geol. Surv. Ind.*, Vol. XL., Part 4, pp. 325, 326 (1910).

book of Geology. He states:[13] "The fossils of the coal-bearing strata of the Carboniferous system are very different, considered *as a group*, from the fossils of the Mountain Limestone and the other purely calcareous beds already described. While the organisms of the limestones are all marine and the inhabitants of salt waters, the fauna of the shaly and carbonaceous beds is indicative of *estuarine* or *brackish-water* conditions, and their flora is as distinctly a *land flora*, evidencing the existence of large tracts of dry land. While this is generally and typically the case, layers containing marine fossils are often interbedded with layers affording the brackish-water and land-derived forms, so that it would appear that not only were most of these areas of deposition open to the ocean, but that at times their waters became so clear and so salt that the ordinary marine fauna was able to exist and to flourish within them. The most abundant of the estuarine forms are the mussel-like *Anthracosia* (*A. carbonaria*) and *Anthracomya*, often found in numberless individuals in the so-called 'mussel-binds' or 'mussel-bands' of the miners. The marine forms occasionally met with are *Productus*, *Spirifer*, *Aviculopecten* (*A. papyraceus*), and *Encrinites*, etc., which are common in the lowest or Gannister division, and rare in the highest beds of the series."

The occurrence of bands of torbanite in the upper coal measures of North Staffordshire and the seepages of oil that occur low down in the coal measures in the same district would appear to correspond to the fact that marine conditions "are common in the lowest or Gannister division and rare in the highest beds of the series."

It is possible that the general question of whether oil-shale or liquid petroleum deposits would be formed might depend not only on whether the deposits were accumulated under fresh-water or brackish-water conditions as against marine conditions, but also on the physical condition of the oily material that was incorporated in the sediment. It seems possible that more or less solid resinous material, and certain resinous spores of plants, might not be acted upon easily by the sulphur-making oil-producing bacteria even if incorporated in a mud deposited under marine conditions, in which case oil shales would be formed in preference to liquid petroleum even though the sediments were accumulated under marine conditions. It would seem, therefore, that although oil shales may be expected in preference to liquid petroleum in strata accumulated under brackish-water or fresh-water conditions, the question of whether liquid petroleum deposits or oil-shales may be expected in detrital desposits accumulated under marine

[13] Charles Lapworth, "Intermediate Text-book of Geology," p. 263 (1889.)

conditions would depend largely on the oily or resinous material originally incorporated in those sediments.

The result of considering all the clues that remain in oil deposits and of reconstructing, as far as possible, the history of events that took place in connection with the deposition of the sediments that now contain oil deposits would appear to be, therefore, the evolution of a working hypothesis as regards the origin of certain kinds of oil deposits which will explain many things that have hitherto lacked explanation. and it is as a working hypothesis that it is put forward. Doubtless many links in the chain of evidence are missing, and doubtless future discoveries will modify the suggested history of events in many details, but it seems that the circumstantial evidence is sufficiently strong to be used by the geologist as a working hypothesis in his search for oil. It has the advantage that it fits in with the natural laws governing the accumulation of geological strata of sedimentary origin, and that it does not include the assumption of something dark and mysterious taking place deep down beneath the earth's surface under the cloak of Metamorphism. Assuming it as a working hypothesis, the following working hypotheses in the geological search for oil would follow as a natural sequence .—

(a) All dolomitised limestones of lagoon formation are worthy of thorough investigation, provided that they prove, on microscopic examination, to be foraminiferal. In this connection it should be noticed that an oil-bearing limestone of this kind need not display much evidence of the presence of oil in its natural outcrops. For example, R. K. Richardson, in his paper on the Geology and Oil Measures of South West Persia, referring to the Asmari Limestone says, "the limestone displays little evidence of being an oil container in its natural outcrops."[14]

(b) If the carbon-ratio of a coal seam deposited under estuarine or fresh water conditions is suitable, as defined by Fuller, then the seam will probably pass gradually through torbanite into oil shale when traced in the direction from which the material forming the seam was originally derived.

(c) In the case of such coals deposited under marine conditions the lateral variation will be into either liquid petroleum deposits or into oil shale, depending on the particular vegetable oil or resinous material originally incorporated in the sediment.

[14] *Journ. Inst. Petr. Tech.*, Vol. X., No. 43, p. 262 (1924).

(d) When formations containing abundant fossil-wood occur the underlying marine formations may contain liquid petroleum.

The reasons for this last hypothesis were outlined by the author in his discussion on "The Relationship of fossil-wood to oil," published in *Economic Geology*, Vol. IX., No. 6, pp. 594-597, (1914), and elaborated in his paper on the "Suggested origin of the oil-bearing strata of Burmah," recently published in the Journal of this Institution.[15] This present paper carries the suggestion the final step and suggests how the vegetable oil may have been converted into petroleum.

It will be seen from the above four working hypotheses that before a definite decision can be come to it is necessary not only to have a thorough knowledge of the stratigraphy of a country but also of the Historical geology of the country, and in addition in the case of coal seams or fossil-wood occurring to know whether the vegetation from which these were derived contained any appreciable quantity of oily material or not. In particular the author would lay stress on the importance of working out the Historical geology, as it would seem that only by a clear understanding of the distribution of sea and land and of the conditions obtaining at the time formations were laid down can a reasonable decision be come to as to whether the formations are likely to be oil-bearing or not, and, if so, where. For instance, when the conditions under which the Lower Carboniferous of Great Britain accumulated are visualized, and the working hypotheses deduced in this paper are applied, the bituminous shales of the Central Lowlands of Scotland seem to fit harmoniously into the general arrangement of the deposits accumulated at that time. In the neighbourhood of the Bristol Channel almost the whole of the Lower Carboniferous is composed of Carboniferous Limestone, with a thin band of shales at the base. In North Wales only the lower half consists of Carboniferous Limestone and the upper half of calcareous shales (Yoredale beds). In the south parts of the Pennine Range the Carboniferous Limestone and overlying Yoredale sandstones attain their maximum thickness. In the Northern Pennines almost the whole of the Lower Carboniferous is represented by sandstones and shales, with the exception of a few persistent beds of limestone in the upper half, while occasional seams of coal make their appearance about the middle of the series. In the Central Lowlands of Scotland the Lower Carboniferous is divisible into two divisions, the lower of which consists of two members—an inferior or *Red Sandstone* group, and a superior or *Cement-stone* group made up

[15] *Journ. Inst. Petr. Tech.*, Vol. XI., No. 50, pp. 295–304 (1925).

of white and yellow sandstones, rare limestones, black shales, thin coal seams, and bituminous shales. The upper division of the Lower Carboniferous of Scotland is usually referred to as the Carboniferous Limestone Series of Scotland, but it answers more accurately to the Yoredale group of the Pennines. The characters of this Lower Carboniferous of Scotland are clearly indicative of the existence of shallow-water and estuarine conditions, while large parts of the more southerly English region remained submerged below the clear waters of the more open seas in which the massive Mountain Limestone was laid down.[16] The material composing the detrital sediments therefore clearly came from the north and was carried into an estuary which opened to the sea towards the south. In the most northerly sediments now remaining bituminous shales and thin coals occur, deposited under estuarine conditions, these pass into workable coals in the Northern Pennine district, and these in turn pass into the massive limestones of the more southerly exposures.

Before closing this paper the occasional association of oil with rock salt deposits may be mentioned. Now there is nothing in the hypothesis as to the origin of certain oil deposits deduced in this paper to connect the formation of oil deposits with the accumulation of beds of rock salt. Rock salt must presumably have been deposited as the result of the evaporation of salt lakes. This suggests the possibility that a stagnant salt lagoon might, by a continuation of the earth movement that cut it off from open circulation with the ocean, become slowly converted into a salt lake in which, as a result of evaporation, deposits of rock salt accumulated. In other words conditions under which dolomitised limestone accumulated might slowly change into conditions under which rock salt was being deposited under inland evaporating salt lake conditions. For instance the change from the conditions under which the Asmari Limestone of South West Persia accumulated into the conditions under which the strata of the Lower Fars Series accumulated shows a change in this direction. Although the two years the author spent investigating, the rock salt deposits of the Punjab and North-West Frontier of India convinced him that there is no genetic relationship between the salt deposits and the occurrences of oil in that part of the world,[17] it seems possible that in certain cases in the world deposits of rock salt may overlie formations containing dolomitised limestone of lagoon formation containing oil. Now the author, as well as other investigators in other parts of the world, found that rock salt deposits can obviously

[16] *Cf.* Charles Lapworth, *loc. cit.*, pp. 252–253 and 270–271.
[17] *Rec. Geol. Surv. Ind.*, Vol. L., Part 4, pp. 263–267 (1919).

become plastic and flow under the influence of earth movements as is shown by the flow structure exhibited by certain rock salt deposits,[18] and consequently when oil is discovered along the margins of salt deposits or salt domes, it seems worth while, when the source of the oil is not obvious, to see whether there is a dolomitised limestone of lagoon formation situated at a geological horizon close below that to which the salt originally belonged. The above is not put forward as a working hypothesis but as worthy of consideration. The above discussion of the occasional association of rock salt and oil does not include the occurrence of the salt water in water-sands in oilfields, which was discussed by the author in his paper on the Sedimentary Deposition of Oil in 1910,[19] and does not seem to need further explanation beyond emphasizing the fact pointed out by Mr. Ernest Clark in his paper on the origin of oil, published in this number of the Journal, that the characteristic differences of such waters from modern sea water are "increased salinity and deficiency in sulphates." This may be expressed in another way, namely, deficiency in sulphates and in H_2O molecules. It is hardly necessary to point out that this difference is exactly the result that would be produced by the bacterial action and processes, outlined by the author in this paper, in the interstitial sea water of marine oil-bearing sediments. In conclusion the author would exclude the various asphalts and asphaltites from present consideration as not coming within the scope of this paper.

[18] *Rec. Geol. Surv. Ind.*, Vol. L., Part 1, pp. 28–97 (1919).
[19] *Rec. Geol. Surv. Ind.*, Vol. XL., Part 4, p. 326 (1910)

The Liability to Explosion of Carburetted Atmospheres in Petroleum and Distillate Storage Tanks.

A. Williams-Gardner, B.Sc.(Tech.).

In the course of an investigation into fire dangers on petroleum refineries an examination was made of the atmospheres existing in storage and process tanks containing inflammable volatile liquids. The particular tanks examined were being continuously emptied and filled with liquid, and samples of their atmospheres were taken when filling, emptying and during the short periods when the contained liquids were in a state of quiescence. It was considered that the results of analysis of these samples would furnish data indicating the extent to which such tanks were in danger of exploding, given the necessary source of ignition, for example, lightning. The investigation was carried out during the month of October when the tank atmosphere temperatures were in the neighbourhood of 17° C. in the majority of cases.

The method of procedure was as follows.—A 4-ounce bottle was fitted with a cork and a short length of glass capillary tubing, both of which were well waxed together and to the bottle to obtain gas-tightness. These sample bottles were connected to an efficient oil pump and evacuated as completely as possible, being then sealed with rubber pressure-tubing and a screw clip. A length (18in.) of pressure-tubing was suspended through the "dip-hole" of a particular tank and swept out with tank atmosphere by means of a hand suction bellows. The sample bottle was then connected to the rubber tubing, the pinch cock quickly opened and closed, the tank atmosphere temperature, tank number, contents and state (whether filling, emptying or quiescent) noted. The sample was then set aside for analysis. These samples were taken about half way through the process of emptying or filling a tank.

Examination and analysis of the gas samples so obtained was carried out on a Bone and Wheeler gas analysis apparatus. The explosion vessel on such an apparatus is cylindrical and has its source of ignition (two platinum points connected to an induction coil and battery) at the top. When the pressure of the gas sample was adjusted to that of the outside atmosphere the internal shape of the explosion vessel was therefore not very dissimilar from that of a tank.

No sample examined was found to be an explosive mixture of air and hydrocarbon vapour at atmospheric temperature and pressure. The total hydrocarbon content was obtained by an explosion analysis : a known quantity of the sample was mixed with a known and adequate quantity of a 50 per cent. air—50 per cent. oxygen mixture free from carbon dioxide and completely exploded. The contraction in volume (C) on explosion and subsequent contraction (A) on removal of carbon dioxide, formed by the combustion of the hydrocarbons, by absorption in aqueous caustic potash were measured. Then the total volume of paraffin hydrocarbons present (V) is given by the equation

$$V = \tfrac{1}{3} (2\,C - A)$$

from which the percentage hydrocarbon content (by volume) of the sample may be calculated. The liquids in the tanks from which the samples were taken were such that the hydrocarbons present in the tank atmospheres could be considered to be entirely composed of paraffin hydrocarbons.

The ratio C/A, where C and A are the values obtained as described above, is found to vary with different paraffins, decreasing in value as the number of carbon atoms in the molecule increases. Thus the lower (gaseous) members of the series have the following values :—

	Hydrocarbon.	C/A ratio.
Methane	CH_4	2·00
Ethane	C_2H_6	1·25
Propane	C_3H_8	1·00
Butane	C_4H_{10}	0·875
Pentane	C_5H_{12}	0·80
Hexane	C_6H_{14}	0·75

Thus the C/A ratio obtained as above is a rough indication of the size of the paraffin molecules present. The exact proportion of the individual members of the series present in a sample of gas can be obtained by explosion analysis only when not more than two members are present. For the determination of the exact proportion of more than two paraffins in a mixture, liquefaction and fractional distillation is necessary. This, however, would require larger samples of gas than were obtained in the present investigation. The value of the C/A ratio may, however, be such as to justify, for the purpose of an approximate result, the assumption that two members only are present at a time. For the purpose of calculating the probable limits of inflammability of mixtures of air and inflammable liquid vapours as described hereafter, the above assumption has been made.

From a consideration of the chemical reactions taking place when a mixture of any two consecutive paraffins and oxygen combine

under conditions of complete combustion the following relationships may be derived :—

For a mixture containing ethane and propane :
Ethane = 2 (C—A)
Propane = 1/3 (5 A—4 C)
For propane and butane :
Propane = 1/3 (8 C—7 A)
Butane = 2 (A—C)
For butane and pentane :
Butane = 1/3 (10 C—8 A)
Pentane = 1/3 (7 A—8 C)
For pentane and hexane :
Pentane = 4 C—3 A
Hexane = 2/3 (4 A—5 C),
where C and A have the same significance as before.

The limit of inflammability (L) of a mixture of paraffins may be calculated, if the nature and proportion of the individuals is known from the equation

$$L = \frac{100}{\frac{P_1}{N_1} + \frac{P_2}{N_2}}$$

where P_1 and P_2 are the proportions of the individual combustible gases in the mixture (so that P_1 and $P_2 + \ldots . = 100$) and N_1, $N_2 \ldots$ are the values of the upper or lower limits for each combustible gas separately, depending upon which mixture-limit is required. The explosive limits for pure paraffins mixed with air are as follows :

Hydrocarbon.	Limits of Inflammability. (% Air by volume.) Lower.	Upper.
Methane	5·6	14·8
Ethane	3·1	10·7
Propane	2·2	7·3
Butane	1·6	5·8
Pentane	1·4	4·5
Hexane	1·2	3·3

Explosion analyses of the samples of gas taken from tanks gave such high values for the C/A ration that in every case other than that of aviation spirit vapour it could be assumed, for the purpose of calculating the theoretical explosive limits, that butane and pentane only were present. In the case of aviation spirit the C/A ratio indicated that pentane and hexane predominated. In each case the percentage of total paraffins present in the atmosphere samples was found to be greater than the calculated value of the upper limit, for those mixtures. The results of the analysis of the samples, together with calculated data, are given below. In those cases where an explosion analysis was not obtained the total hydrocarbon content was obtained from the percentage of oxygen present, as determined by absorption with alkaline pyrogallol.

Contents of tank.	State.	Vol. % on total atmos. Total Hydrocarbons (at 45° C.).	Butane.	Pentane.	C/A ratio.	Cal. limits. Lower.	Upper.
Treated No. 1 Spirit.	F	10·8	6·7	4·1	0·86	1·5	5·0
„ „ „	Q	5·05	2·25	2·80	0·829	1·5	5·0
„ „ „	E	5·81					
Untrtd. „ „	E	7·06					
„ No. 3 „	F	11·9					
„ „ „	Q	10·6	8·3	2·3	0·849	1·6	4·8
„ „ „	E	9·7					
O.R.D. ..	F	9·2					
Treated „ ..	Q	8·4	6·5	1·9	0·856	1·6	4·8
„ „ ..	E	8·75					
Crude Oil	F	6·35	5·6	0·75	0·864	1·6	5·6
„ „	E	6·73					
			Pentane.	Hexane.			
Aviation Spirit ..	Q	5·05	3·44	1·61	0·782	1·3	4·1

The high atmospheric temperature in this tank was due to a leaking steam pipe.

F = Filling. E = Emptying. Q = Quiescent.

The limits of inflammability obtained by calculation for the above distillates compare very favourably with some actual experimental determinations carried out on gasolines by Burrell (J. Ind. and Eng. Chem. Vol. 7, No. 5, p. 414), when the figures 1·5 (lower) and 5·2 (upper) were obtained for a gasoline of specific gravity 53° Baumé scale. This, together with the fact that in no case could a sample of tank atmosphere be exploded, tends to justify the assumptions made in the above calculations.

It is quite possible that, in cooler weather than that in which these samples were taken, and in the case of extremely fast emptying of tanks, explosive mixtures of hydrocarbon vapours and air may occur. In moderate and warm weather, however, the existence of an explosive atmosphere in a tank would appear to be unlikely, the atmospheres tending to be too rich in hydrocarbons to allow flame propagation.

An interesting point arises from the above experiments, namely, that, as the specific gravity of the tank contents increases, the C/A ratio of the vapours increases in value. In other words, the hydrocarbons present in the tank atmospheres incline to consists of a higher proportion of the lowest paraffins. Thus in the case of O.R.D. there is a higher proportion of butane to pentane than there is in the case of No. 1 spirit. In the case of aviation spirit it is probable that pentane and hexane exist in the superincumbent atmosphere almost to the complete exclusion of butane. This may be explained by the fact that the aviation spirit consists of the most part of pentane, hexane, and heptane in which the gaseous paraffins are not very soluble, whereas No. 3 spirit, which contains heavier

paraffins, is capable of dissolving permanent gases liberated during the process of distillation on the refinery, and thus make their appearance in the storage tanks during evaporation.

In conclusion the author wishes to acknowledge much useful advice with regard to this work given by Professor R. V. Wheeler, and to thank Dr. A. E. Dunstan of the Anglo-Persian Oil Company for his kind permission to publish the results.

STUDENTS' SECTION, LONDON BRANCH.

A MEETING of the London Branch of the Students' Section of the Institution of Petroleum Technologists was held at Aldine House, Bedford Street, London, W.C. 2, on Tuesday, March 16th 1926, and a summary of the paper read follows :—

Electrical Methods of Prospecting for Oil.

By J. O. TANNER, B.A. (Cantab).

OIL finding by Geophysical methods, may broadly be divided into four branches :—

Electrical.
Magnetic.
Seismic.
Gravimetric.

That is upon the electrical conductivity, magnetic permeability, modulus of elasticity, and specific gravity of the sedimentary, and igneous rocks, comprising the surface of the earth.

Electrical prospecting methods can be divided into two principal groups, potential methods, and electro-magnetic methods. Potential methods are based upon the investigation of the distribution of the potential, in an electrical field, by tracing equipotential lines, or measuring differences in potential between different points.

Electro-magnetic methods are based, on causing a current to flow through the mass to be examined, and then examining the disturbances in the electro-magnetic field, caused by this current.

The methods can according to the manner of causing the current, be divided into :—

(1) Methods in which the current is caused to flow in the mass *inductively*, that is by means of closed cables insulated from the ground.

(2) Methods in which the current is caused *galvanically*, that is by means of wires connected with the ground ; in this case an electrical current is also caused inductively by the cables.

(3) Methods in which the current is transmitted *capacitively*, that is by means of open wires, which are insulated from the ground, for instance an antennæ. These methods also include wireless methods.

Brown patented in 1900, a method by which mineral lodes could be discovered, by the difference in resistance which an electric current encounters, when it passes through a metallic mass, or through country rock.

Daft and Williams, in 1902, patented a method by which they observed the variations in sound, of an alternating current, which was sent through the ground to be explored.

M. Gunner Bergstrom and Carl Berghlomn also did valuable pioneer work in this respect.

It was not, however, until C. Schlumberger, Professor of L'Ecole Nationale Superieure des Mines, published his classical work on this subject, that a real impetus was felt, and that the subject was brought to truly scientific basis.

The principle of the potential method, as outlined by Schlumberger is as follows. When one applies between two points, A and B, a difference of potential there is a flow of electricity.

If, for instance, the current flows from A to B, the potential falls in the same direction.

When a current enters a wide conductor, it never takes the path of least resistance; instead of flowing in one line, it spreads out, and flows through the mass of the conductor.

At every point, the direction of electrical flow, is normal to the equipotential surfaces.

The density of the current, and with it the intensity of the electric field, varies as the square of the distance from this point.

To represent points of equipotential, through the mass, it is easier to consider them as equipotential surfaces, and to number them accordingly.

If one considers the phenomena, as it would appear on the surface, the only one which is practically observable, it is seen that it is possible, over all the area under observation, to trace out equipotential lines, which are the surface indications, of the potential surfaces at depth, and that each of these lines, is capable of possessing a fixed value.

These numbered potential lines, constitute a potential map of the region, which is similar in principle to a topographic map, where differences in height are indicated by contour lines.

When the ground is homogeneous, the distribution of the potential surfaces can be calculated, which is the same as saying that the potential is known beforehand.

When the ground contains rocks and minerals of different conductivity, there is a modification in the distribution of the potential surfaces, bringing about perturbations, which influence to varying degrees, the position of the potential lines on the surface.

Now these potential lines may easily be traced on the surface, and the deformation plotted. From the lack of symmetry, it is possible with experience, to deduce the causes.

When the ground instead of being homogeneous is made up of zones of different conductivity, this will affect the lines of equal potential.

Supposing, for instance, that between A and B, buried at a depth, is a perfectly conducting mass Z. The mass is in this condition everywhere at equal potential.

The equipotential lines have a tendency to envelope the conducting mass; in other words, the mass acts as if it pushed outwards towards its exterior, all equipotential surfaces.

If instead of being a perfect conductor, the mass Z still has a greater conductivity, than the surrounding area, the same tendency will be felt, though to a lesser degree.

Let us now take the opposite case of a mass having no conductivity. In this case the electric flow is forced to make its way round, causing the equipotential surfaces to cut the surface of the mass at right angles.

One could consider that a non-conducting mass tends to pull the equipotential surfaces towards itself.

This attraction would become less obvious, but would still exist if Z, instead of being a non-conductor, had a greater resistance than the surrounding rock mass.

Assuming, which we may do, with fair safety, that an oil saturated sand is a bad conductor, it will be seen that it will modify the flow of an electrical current, in a similar manner to that which we have explained above for a non-conducting mass.

It is possible, however, to work out concealed structure, and thus in an indirect way to disclose the presence of oil.

Let us consider a series of stratified rocks, outcropping vertically. We place on the surface one electrode A, and we place the other B at a distance.

The equipotential surface around the point A at depth is not a sphere, as in an isotropic mass. It can be shown that it is a flattened ellipsoid of revolution, around the perpendicular Ax.

If one considers not the interior potential surfaces, but their trace on the surface, one sees that it is an ellipse, whose long axis is longer in the direction of stratification. If now we suppose that the beds are not vertical, but tilted at a definite angle from the horizontal, the ellipse will tend to become more symmetrical, and if the beds are horizontal the trace of the equipotential lines, on the surface, will be a circle.

Now consider that the beds are overlain by an overburden of new horizontal rocks, or of glacial drift.

In this case the lines of equipotential will be unaffected as long as their radius does not impinge into the underlying tilted beds.

As soon, however, as the radius of potential surfaces from A exceeds the depth to which the tilted beds are buried, the anisotropic nature and character of the tiled beds will distort the equipotential surfaces, the overlying isotropic mass will not compensate this distortion, and it will be possible to plot the ellipse formed on the surface.

Professor Schlumberger has observed by this method, in Normandy, the strike of steeply inclined Palaeozoic strata, under an overburden of flat Jurassic formations of 2-300 ft. in thickness.

Surface moisture may have an influence on the equipotential lines. It can be shown, however, that this is far less than is generally thought to be the case, and that the presence of marshes, rivers, etc., have very little influence on the general distribution of equipotential lines.

Amongst the most widely advertised instruments are W. Mansfield's "Patent automatic oil and water finder," and Adolf Schmid's "Device for detecting subterranean waters." Mansfield's instrument was denied a patent in the U.S.A. on the ground that it was anticipated by the patent of A. Schmid's.

In the letters patent of the Schmid's device it is stated that the apparatus will indicate certain atmospheric changes, the nature of which are not yet understood, but which manifest themselves in a peculiar way at the source and course of subterranean waters by rapid oscillation of the pointer of the device.

The instrument is described as a hollow glass cylinder, having an axis, around which is spirally wound a soft-iron wire in layers, that are separated from one another by paraffined paper, and at intervals by layers of tin foil. The outside layer of the spool is covered with paper. The wire of this spool forms an open circuit. The end of the spool is covered with a glass dial plate, having at its centre a pivot on which a pointer or needle oscillates.

It is claimed that when the instrument is in the vicinity of a source, or a stream of subterranean water, the needle will after a time oscillate rapidly.

In the literature advertising its "Automatic oil and water finder," circulated by the Mansfield Company of Liverpool, the following claims are made:

The principle on which the instrument works is the indicating of the presence of currents which flow between earth and atmosphere, and which seeking the paths of greatest conductivity are always strongest in the vicinity of subterranean water courses, the waters of which are charged with electricity to a certain degree.

The instrument is tried over various likely spots, and should the

needle move at any one of them tests are made all round it, and the spot where the greatest movement is obtained is where the boring should be made.

It is difficult out of the mass of controversial and differing opinions to come to any sound conclusion on this instrument.

Professor Schlumberger, and others, have shown that natural electric currents are found above underground water in motion, especially if it is passing through capillaries; for instance, in motion through a sand, but up to now it has been difficult to see how an oil pool would cause similar reactions.

Mr. Burton shows in a paper published in the Philosophical Magazine, Vol. 8, 1904, that a highly radio-active gas was obtained from crude petroleum.

The general conclusion which the authorities on this subject have come to is that the radio-activity of petroleum must be due to Radium.

There is, therefore, sufficient evidence that an oil pool might be the seat of electrical disturbances.

Firstly, there is the known presence of Helium found dissolved in petroleum, and also in the gas. It is difficult to explain the presence of this substance, except by realising that it is a product of radio-active decomposition.

Secondly, G. F. Becker has called attention to the fact that oil fields in the U.S.A., especially in the Appalachian district, are characterised by magnetic anomalies of the declination.

He explained this by the presence of deeply buried masses of iron-carbide by which he wished to advance the inorganic origin of oil.

How much more simple, however, would be the explanation that these anomalies are due to the presence of electrical currents flowing out from these areas.

Electro-magnetic observations are of more recent date, being tried for the first time in 1909.

The *galvanic* method, which is perhaps the simplest, consists chiefly in the determination of H, which is the horizontal component of the secondary field, raised as a result of the current through the mass.

The *inductive* method is chiefly concerned with the distribution and course of the electro-magnetic field generated by the induced current flowing through the mass.

The *capacitive* method.

Hertzian waves are able to travel through dielectrics whilst they are absorbed or reflected by conducting masses.

The practical methods employed have been chiefly studied by Lowy and Liembach, who have taken various patents and published a series of works.

Lowy and Liembach have also shown that the high-frequency oscillating current in an aerial is affected by neighbouring conducting masses.

A second method, suggested by Taussig, is based on the principle that electro-magnetic waves are reflected by a conductor.

An aeroplane, or airship, equipped with a transmitting and receiving set could thus be able to send out an electro-magnetic wave front, and observe whether it was reflected or not, thus indicating the presence, or absence, of a conducting body.

Sundberg has devised a method by means of a movable receiving antennæ. He gauges the strength J. of current received from a distant station. Besides depending on the distance from the transmitting station J. as can be shown also depends on the specific conductivity and di-electric constant of the subterranean material.

We have thus given a brief review of the various electrica methods at present employed, some of which could be put to advantage for the detection of oil pools.

With the decline in production, which will inevitably take place in the future, the oil industry cannot afford to overlook methods which could help it in discovering those pools which, due to lack of indications, have escaped detection.

It is just in these cases that electrical methods are at their best; this is common with other geophysical methods. Electrical methods, however, possess over other geophysical methods the advantage of being simple in manipulation, and it is high time that greater use be made of these methods.

A discussion followed, in which Mr. E. Clark, Mr. W. H. Fordham, Mr. E. H. Cunningham-Craig, and Professor V. C. Illing took part.

REVIEWS.

LES PROPRIETES PHYSIQUES DES VAPEURS DE PETROLE ET LES LOIS DE LEUR ECOULEMENT. Par M. Jean Roy, Ingenieur civil des Mines, Laureat de l'Institut. (Extrait des Annales des Mines, Libraisons de Juillet, Aout et Septembre, 1925.)

The study of the physical properties of the vapours of petroleum has progressed very little beyond simple determinations of density, flash point and calorific value. In France, Pelouze and Cahours determined specific gravity, boiling points and vapour densities for American petroleum, whilst in Russia, Medeleef made analagous observations on Caucasian petroleum, Mabery in America, in 1921, published elaborate memoirs on the properties of Pennsylvanian and Californian mineral oils. Mabery concentrated on the chemical composition, molecular weight, refractive index, boiling point, specific heat and to a less extent the heat of vapourisation. In Italy, M. Bartole Stracciati made a number of experiments on the critical temperatures and molecular volumes of the hydrocarbons in Pennsylvania crude. The bulk of the above researches are discussed in the Tables Annules Internationales des Constantes, 1910. The present author has studied, since 1896, the physical properties of mineral oils and more particularly of kerosene. He justly points out that the engineers who design internal combustion engines, heating apparatus, etc., have the most limited data to go on. Neither the heat or vapourisation nor the entrope diagram are accurately known, and he has set out to fill the gaps. His valuable monograph gives a mathematical and experimental treatment of the following subjects :—

The Tension of the Saturated Vapour of Kerosene.
The Heat of Vapourisation.
Specific Gravity and Specific Volume.
Specific Heat under Constant Pressures.
Rate of Diffusion of Kerosene Vapour.
The Entrope Diagram.
The Characteristic Function.

The latter half of the book deals with the burning properties and methods of combustion, together with the experimental methods of determining physical properties.

A. E. D.

SCHLOMANN-OLDENBOURG. Illustrated Technical Dictionaries in Six Languages. German, English, French, Russian, Italian and Spanish. Vol. IV. Internal Combustion Engines. Compiled by Dipl.-Ing. Karl Schikore. (Lewenz and Wilkinson,. Ltd., 25, Victoria Street, London, S.W. 1.)

The little volume before us is a part of a series of illustrated lexicons dealing with a wide range of technical subjects. The branch of engineering with which the present volume deals—i.e., internal-combustion engines—has seen an enormous development recently and a considerable technical literature has been accumulated. From this literature from catalogues and the prospectus of numerous manufacturers the compilers have collected a large number of definitions and special terms. Not only individual words but also phrases of technical importance have been incorporated. The material dealt with includes gases and oils: the theory of internal-com-

bustion engines, materials and manufacture, construction and equipment of engines, erection and foundations, stationary and portable plants, working, testing and economics. One or two examples may be given of the scope of the work:—

The inclined face of a tooth.
Timing by means of an eccentric pin.
Superheated alcohol carburetter.
Arrangement of cam shaft.
Two-stroke cycle operation.
The efficiency of gas production.
Equilibrium ratio between CO and CO_2.

The book is amply indexed in each of the six languages, is very well got up and of a handy size, but the line drawings are of very doubtful value.

A. E. D.

THE OIL INDUSTRY. By E. R. Lilley. London: Constable and Co., 1926.

The author has written an exceedingly interesting and comprehensive summary of the industry as a whole. He points out that each group of workers is familiar with the particular problem appertaining to their own particular section, but feels that there is a need for a comprehensive summary, seeing that the industry is now so large, and the work of its various divisions is so specialised that it is scarcely possible for any one man to keep personally in touch with the problems of all. The author hopes that the volume he has written will give an accurate and unbiassed account of the problems that have been faced and solved in all branches of the oil industry.

A survey of the chief sections into which the book is divided is a testimonial to the catholic knowledge possessed by Professor Lilley. As a geologist he perhaps devotes rather too much space to the application of that science of petroleum, but on the other hand the information he has put forward in connection with refining and distribution are accurate and and concise. Rather more than half the book is occupied with the sections dealing with exploration, drilling and the oilfields of the United States, Canada, Mexico, Cuba, South American and the Eastern Hemisphere. Following this are chapters on storage, transportation, natural gas and gasoline, refining, cracking and an informative discussion on petroleum substitutes and the future prospects of the industry.

Each chapter is provided with a short bibliography, so that further information may be readily sought for. The book is admirably produced, and the printing and general get up are beyond reproach. The photographic illustrations add greatly to its value, and it will be found useful, not only to those actually in the industry but to the general reader who desires a bird's-eye view of all the operations involved in the production, refining, distribution and economics of petroleum.

A. E. D.

CHEMICAL ENGINEERING AND CHEMICAL CATALOGUE. Edited by D. M. Newitt. 2nd Edition. Pp. 360. London: Leonard Hill. 1926.

The second edition of this useful reference work of chemicals and chemical plant shows a considerable advance over the first edition. The Classified Index of Chemicals and Plant occupies 113 pages. The primary use of the index is in reference to the catalogue section contained in the following 160 pages, but it also includes the names of manufacturers not using space in that section. The list of mineral oil suppliers and plant manufacturers has been enlarged somewhat over the previous edition, but we still note many

omissions, particularly under the headings of Fuel Oil, Lubricating Oil and Oil Refining Plant.

After the catalogue section is a short article by Sir Robert Hatfield, Bart., on "Corrosion," and this is followed by twenty-seven pages of general data and tables of considerable use to those engaged in chemical work.

The B.E.S.A. specifications for steam jacketed pans and filter plates and frames are included, and the work concludes with an index of industrial application of chemicals and chemical plant arranged under headings of various trades.

The work is one which can be recommended as a useful technical reference book to all engaged in the chemical and associated industries.

G. S.

PETROLEUM-VADEMECUM. INTERNATIONAL PETROLEUM TABLES. Ing. R. Schwarz. 3rd Edn. Verlag für Fachliteratur, Berlin, 1926. 15 Marks.

This book contains a number of tables for the conversion of the various weights and measures used in the petroleum industry. It also includes tables of Baume and specific gravity equivalents; comparison of Engler, Redwood and Saybolt viscosities; price and freight rate conversions from dollars per barrel or shillings per ton to dollars per 100 kilos. at various gravities; and rate of exchange conversions. Over 100 pages are devoted to tariff rates for mineral oils in various countries, and statistics relating to the production, import and export of oil in various countries are given.

While the main parts of the book are written in German, the table headings and other necessary data are also given in English and French, and the work, which is of convenient size for carrying in the pocket, should prove of value to those who require to obtain quick and fairly accurate conversion of petroleum weights and measures. G. S.

BOOKS RECEIVED.

THE LANCASHIRE COALFIELD: THE KING SEAM. Department of Scientific and Industrial Research. H.M. Stationery Office, 1s. 6d. net.

This is the sixth of the series on the physical and chemical survey of the national coal resources, and describes laboratory experiments on the King Seam of Lancashire, carried out by the Lancashire and Cheshire Coal Research Association.

The King Seam varies in thickness and quality and in some districts contains a large number of dirt bands. Volatile matter ranges from 36 to 43 per cent., sulphur from 1.5 to 3.5 per cent., and calorific value from 13,650 to 14,290 B.Th.U. per lb. Representative samples of the whole seam, excluding shale and dirt bands, were subjected to carbonisation tests at 600° C., and showed it to be suitable for low-temperature carbonisation without blending.

CURRENT PETROLEUM NOTES.

Nova Scotia.—Messrs. Oil and Nitrate Products, Ltd. have recently completed negotiations whereby the development and production of oil and other products from the oil shales of Picton country are to be undertaken.

Alberta.—It is anticipated that over fifty oil companies will be drilling in the Turner Valey area before the end of the summer. Drilling operations in other fields are also to be advanced and more than a dozen are projected for the Ribstone-Blackfoot district.

As a result of the report of Dr. G. S. Hume, Dominion Geologist, indicating favourable oil prospects between Ribstone and Lloydminster, there was a rush to take up leases in the new field.

In order that the product from the Royalite No. 4 well, 35 miles south-west from Calgary, might be dealt with efficiently and waste prevented, a total expenditure of about $660,000 has been made. The well has a daily flow of 18,000,000 cubic feet of natural gas, which yielded, in 1925, about 166,000 barrels of crude naphtha of 73° Bé gravity. The naphtha is pumped to the refinery at Calgary through a pipe-line recently completed at a cost of about $160,000 and is then treated for the elimination of hydrogen sulphide. The gas is also piped to Calgary, the gas-line costing nearly $250,000, where it is used for domestic purposes. From the well the gas is led to the separators, which remove the naphtha, and thence to a scrubbing plant for the removal of the hydrogen sulphide. From the scrubbers, which were erected at a cost of about $250,000, the gas is turned into the mains of the gas company.